

DESCRIPTION

CALCIUM RECEPTOR-ACTIVE MOLECULES

RELATED APPLICATIONS

This is a continuation-in-part of Nemeth et al.,
entitled "Calcium Receptor Active Molecules" U.S. Serial No.
08/353,784, filed December 8, 1994, which is a continuation-
in-part of Nemeth et al., entitled "Calcium Receptor Active
5 Molecules" PCT/US94/12117, filed October 21, 1994, which is
a continuation-in-part of Nemeth et al., U.S. Serial No.
08/292,827, filed August 19, 1994, entitled "Calcium Receptor
Active Molecules" which is a continuation-in-part of U.S.
Serial No. 08/141,248, filed October 22, 1993, entitled
10 "Calcium Receptor Active Molecules" which is a continuation-
in-part of Nemeth et al., U.S. Serial No. 08/009,389, filed
February 23, 1993, entitled "Calcium Receptor Active
Molecules" which is a continuation-in-part of U.S. Serial No.
08/017,127, filed February 12, 1993, which is a continuation-
15 in-part of Nemeth et al., U.S. Serial No. 07/934,161, filed
August 21, 1992, which is a continuation-in-part of Nemeth et
al., U.S. Serial No. 07/834,044, filed February 11, 1992,
abandoned, which is a continuation-in-part of Nemeth et al.,
U.S. Serial No. 07/749,451, filed August 23, 1991, abandoned,
20 the whole of each of these applications including the
drawings are hereby incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to the design, development,
25 composition and use of molecules able to modulate the
activity of an inorganic ion receptor, preferably a calcium
receptor. It also relates to a superfamily of receptors for
inorganic ion (inorganic ion receptors) such as calcium
receptors. The invention also relates to nucleic acids
30 encoding such receptors, cells, tissues and animals
containing such nucleic acids, antibodies to such receptors,

assays utilizing such receptors, and methods relating to all of the foregoing.

BACKGROUND OF THE INVENTION

5 The following description provides a summary of information relevant to the present invention. It is not an admission that any of the information provided herein is prior art to the presently claimed invention, nor that any of the publications specifically or implicitly referenced are
10 prior art to that invention.

Certain cells in the body respond not only to chemical signals, but also to ions such as extracellular calcium ions (Ca^{2+}). Changes in the concentration of extracellular Ca^{2+} (referred to herein as "[Ca^{2+}]") alter the functional
15 responses of these cells. One such specialized cell is the parathyroid cell which secretes parathyroid hormone (PTH). PTH is the principal endocrine factor regulating Ca^{2+} homeostasis in the blood and extracellular fluids.

PTH, by acting on bone and kidney cells, increases the
20 level of Ca^{2+} in the blood. This increase in [Ca^{2+}] then acts as a negative feedback signal, depressing PTH secretion. The reciprocal relationship between [Ca^{2+}] and PTH secretion forms the essential mechanism maintaining bodily Ca^{2+} homeostasis.

25 Extracellular Ca^{2+} acts directly on parathyroid cells to regulate PTH secretion. The existence of a parathyroid cell surface protein which detects changes in [Ca^{2+}] has been suggested. This protein acts as a receptor for extracellular Ca^{2+} ("the calcium receptor"), and is suggested to detect
30 changes in [Ca^{2+}] and to initiate a functional cellular response, PTH secretion. For example, the role of calcium receptors and extracellular Ca^{2+} in the regulation of intracellular Ca^{2+} and cell function is reviewed in Nemeth et al., Cell Calcium 11: 319, 1990; the role of calcium

receptors in parafollicular and parathyroid cells is discussed in Nemeth, Cell Calcium 11: 323, 1990; and the role of calcium receptors on bone osteoclasts is discussed by Zaidi, Bioscience Reports 10: 493, 1990.

- 5 Other cells in the body, specifically the osteoclast in bone, the juxtaglomerular, proximal tubule cells in the kidney, the keratinocyte in the epidermis, the parafollicular cell in the thyroid, intestinal cells, and the trophoblast in the placenta, have the capacity to sense changes in $[Ca^{2+}]$.
- 10 It has been suggested that cell surface calcium receptors may also be present on these cells, imparting to them the ability to detect and to initiate or enable a response to changes in $[Ca^{2+}]$.

In parathyroid cells, osteoclasts, parafollicular cells (C-cells), keratinocytes, juxtaglomerular cells, trophoblasts, pancreatic beta cells and fat/adipose cells, an increase in $[Ca^{2+}]$ evokes an increase in intracellular free Ca^{2+} concentration (" $[Ca^{2+}]_i$ "). Such an increase may be caused by influx of extracellular Ca^{2+} or by mobilization of Ca^{2+} from intracellular organelles. Changes in $[Ca^{2+}]_i$ are readily monitored and quantitated using fluorimetric indicators such as fura-2 or indo-1 (Molecular Probes, Eugene, OR). Measurement of $[Ca^{2+}]_i$ provides an assay to assess the ability of molecules to act as agonists or antagonists at the calcium receptor.

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In parathyroid cells, increases in the concentration of extracellular Ca^{2+} evoke rapid and transient increases in $[Ca^{2+}]_i$ which are followed by lower, yet sustained, increases in $[Ca^{2+}]_i$. The transient increases in $[Ca^{2+}]_i$ arise from the mobilization of intracellular Ca^{2+} , whereas the lower, sustained increases result from the influx of extracellular Ca^{2+} . The mobilization of intracellular Ca^{2+} is accompanied by increased formation of inositol-1,4,5-triphosphate (IP_3) and diacylglycerol, two biochemical indicators which are

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associated with receptor-dependent mobilization of intracellular Ca^{2+} in various other cells.

In addition to Ca^{2+} , various other di- and trivalent cations, such as Mg^{2+} , Sr^{2+} , Ba^{2+} , La^{3+} and Gd^{3+} also cause the mobilization of intracellular Ca^{2+} in parathyroid cells. Mg^{2+} and La^{3+} also increase the formation of IP_3 . All of these inorganic cations depress the secretion of PTH. The postulated calcium receptor on the parathyroid cell is therefore promiscuous because it detects a variety of extracellular di- and trivalent cations.

The ability of various compounds to mimic extracellular Ca^{2+} in vitro is discussed by Nemeth et al., (spermine and spermidine) in "Calcium-Binding Proteins in Health and Disease," 1987, Academic Press, pp. 33-35; Brown et al., (e.g., neomycin) Endocrinology 128: 3047, 1991; Chen et al., (diltiazem and its analog, TA-3090) J. Bone and Mineral Res. 5: 581, 1990; and Zaidi et al., (verapamil) Biochem. Biophys. Res. Commun. 167: 807, 1990.

Brown et al., J. Bone Mineral Res. 6: 11, 1991 discuss theories regarding the effects of Ca^{2+} ions on parathyroid cells, and propose that the results may be explained by both a receptor-like mechanism and a receptor-independent mechanism as follows:

Polyvalent cations [e.g., divalent and trivalent cations] exert a variety of effects on parathyroid function, such as inhibition of parathyroid hormone (PTH) secretion and cAMP accumulation, stimulation of the accumulation of inositol phosphates, and elevation of the cytosolic calcium concentration. These actions are thought to be mediated through a "receptor-like" mechanism. The inhibition of agonist-stimulated cAMP accumulation by divalent and trivalent cations, for example, is blocked following preincubation with pertussis toxin. Thus, the putative polyvalent cation receptor may be coupled to inhibition of adenylate cyclase by the inhibitory guanine nucleotide regulatory (G) protein, G_i .

We recently showed that the polycationic antibiotic, neomycin, mimics the actions of di- and trivalent cations in several aspects of parathyroid function. To determine whether these actions were specific to this agent or represented a more generalized action of polycations, we tested the effects of the highly basic peptides, polyarginine and polylysine, as well as protamine on the same parameters in dispersed bovine parathyroid cells. The results demonstrate that the parathyroid cell responds to a variety of polycations as well as to polyvalent cations, potentially via similar biochemical pathways. These results are discussed in terms of the recently postulated, "receptor-independent" modulation of G proteins by polycations in other systems.

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The Ca^{2+} receptor has been presumed to be analogous to other G protein-coupled receptors [e.g., a glycoprotein], but recent studies with other cell types have raised the possibility that polycations can modulate cell function by alternative or additional mechanisms. In mast cells, for example, a variety of amphipathic cations, including mastoparan, a peptide from wasp venom, 48/80, a synthetic polycation, and polylysine, enhance secretion by a pertussis toxin-sensitive mechanism, suggesting the involvement of a G protein. No classic cell surface receptor has been identified that could mediate the actions of these diverse agents. Furthermore, these same compounds have been shown to activate directly purified G proteins in solution or in artificial phospholipid vesicles. On the basis of these observations, it has been proposed that amphipathic cations activate G proteins and, in turn, mast cell secretion by a "receptor-independent" mechanism.

Polycations have also been shown to interact strongly with acidic phospholipids. Polylysines of varying chain lengths (20-1000 amino acids) bind to artificial phospholipid vesicles with dissociation constants in the range of 0.5 nM to 1.5 μM . The binding affinity is directly related to the length of the polylysine chain, with polymers of 1000 amino acids having a K_d of 0.5 nM, shorter polymers having higher K_d values, and

lysine not interacting to a significant extent. This relationship between potency and chain length is similar to that observed for the effects of polylysine 10,200, polylysine 3800, and lysine on parathyroid function.

It is possible that the binding of polycations to biomembranes produces some of their biologic actions. The permeabilization of the plasma membrane induced in some cell types by a variety of pore-forming agents, including polycations, has been postulated to be mediated by their interaction with a phosphatidylserine-like structure. In addition, the "receptor-independent" activation of purified G proteins by amphipathic cations is potentiated when these proteins are incorporated into phospholipid vesicles.

Calcium ions, in the millimolar concentration range, also produce marked changes in membrane structure. In some cases, calcium can either antagonize or potentiate the interaction of polycations with membrane lipids. These considerations raise the possibility that the actions of both polyvalent cations and polycations on parathyroid cells could involve a receptor-independent mechanism not requiring the presence of a classic, cell surface, G protein-coupled receptor. Further studies, however, are required to elucidate the molecular basis for Ca^{2+} sensing by this and other cell types. [Citations omitted.]

Shoback and Chen, J. Bone Mineral Res. 6 (Supplement 1) 1991, S135) and Racke et al., J. Bone Mineral Res. 6 (Supplement 1) 1991, S118) describe experiments which are said to indicate that a calcium receptor or Ca^{2+} sensor is present in parathyroid cells. Messenger RNA isolated from such cells can be expressed in oocytes and caused to provide those oocytes with a phenotype which might be explained by the presence of a calcium receptor protein.

SUMMARY OF THE INVENTION

The present invention relates to the different roles inorganic ion receptors have in cellular and body processes.

The present invention features: (1) molecules which can modulate one or more inorganic ion receptor activities, preferably the molecule can mimic or block an effect of an extracellular ion on a cell having an inorganic ion receptor, more preferably the extracellular ion is Ca^{2+} and the effect is on a cell having a calcium receptor; (2) inorganic ion receptor proteins and fragments thereof, preferably calcium receptor proteins and fragments thereof; (3) nucleic acids encoding inorganic ion receptor proteins and fragments thereof, preferably calcium receptor proteins and fragments thereof; (4) antibodies and fragments thereof, targeted to inorganic ion receptor proteins, preferably calcium receptor protein; and (5) uses of such molecules, proteins, nucleic acids and antibodies.

The preferred use of the present invention is to treat diseases or disorders in a patient by modulating one or more inorganic ion receptor activities. Diseases or disorders which can be treated by modulating inorganic ion receptor activity include one or more of the following types: (1) those characterized by abnormal inorganic ion homeostasis; (2) those characterized by an abnormal amount of an extracellular or intracellular messenger whose production can be affected by inorganic ion receptor activity; (3) those characterized by an abnormal effect (e.g., a different effect in kind or magnitude) of an intracellular or extracellular messenger which can itself be ameliorated by inorganic ion receptor activity; and (4) other diseases or disorders in which modulation of inorganic ion receptor activity will exert a beneficial effect, for example, in diseases or disorders where the production of an intracellular or extracellular messenger stimulated by receptor activity compensates for an abnormal amount of a different messenger. Examples of extracellular messengers whose secretion and/or effect can be affected by modulating inorganic ion receptor

activity include inorganic ions, hormones, neurotransmitters, growth factors, and chemokines. Examples of intracellular messengers include cAMP, cGMP, IP_3 , and diacylglycerol.

Preferably, the compound modulates calcium receptor
5 activity and is used in the treatment of diseases or disorders which can be affected by modulating one or more activities of a calcium receptor. Extracellular Ca^{2+} is under tight homeostatic control and controls various processes such as blood clotting, nerve and muscle
10 excitability, and proper bone formation. Calcium receptor proteins enable certain specialized cells to respond to changes in extracellular Ca^{2+} concentration. For example, extracellular Ca^{2+} inhibits the secretion of parathyroid hormone from parathyroid cells, inhibits bone resorption by
15 osteoclasts, and stimulates secretion of calcitonin from C-cells.

Preferably, the disease or disorder is characterized by abnormal bone and mineral homeostasis, more preferably calcium homeostasis. Abnormal calcium homeostasis is
20 characterized by one or more of the following activities: (1) an abnormal increase or decrease in serum calcium; (2) an abnormal increase or decrease in urinary excretion of calcium; (3) an abnormal increase or decrease in bone calcium levels, for example, as assessed by bone mineral density
25 measurements; (4) an abnormal absorption of dietary calcium; (5) an abnormal increase or decrease in the production and/or release of messengers which affect serum calcium levels such as parathyroid hormone and calcitonin; and (6) an abnormal change in the response elicited by messengers which affect
30 serum calcium levels. The abnormal increase or decrease in these different aspects of calcium homeostasis is relative to that occurring in the general population and is generally associated with a disease or disorder.

Diseases and disorders characterized by abnormal calcium homeostasis can be due to different cellular defects such as a defective calcium receptor activity or a defective intracellular protein acted on by a calcium receptor. For example, in parathyroid cells, the calcium receptor is coupled to the G_i protein which in turn inhibits cyclic AMP production. Defects in G_i protein can affect its ability to inhibit cyclic AMP production.

The inorganic ion receptor-modulating agents (e.g., molecules and compositions) can be used to treat patients. A "patient" refers to a mammal in which modulation of an inorganic ion receptor will have a beneficial effect. Patients in need of treatment involving modulation of inorganic ion receptors can be identified using standard techniques known to those in the medical profession. Preferably, a patient is a human having a disease or disorder characterized by one more of the following: (1) abnormal inorganic ion homeostasis, more preferably abnormal calcium homeostasis; (2) an abnormal level of a messenger whose production or secretion is affected by inorganic ion receptor activity, more preferably affected by calcium receptor activity; and (3) an abnormal level or activity of a messenger whose function is affected by inorganic ion receptor activity, more preferably affected by calcium receptor activity.

Thus, a first aspect of the present invention features an inorganic ion receptor-modulating agent comprising a molecule which either evokes one or more inorganic ion receptor activities, or blocks one or more inorganic ion receptor activities. The agent has an EC_{50} of less than or equal to 5 μM at its respective receptor and is not protamine. Preferably, the inorganic ion receptor is a calcium receptor and the molecule has an EC_{50} of less than or equal to 5 μM at a calcium receptor and is not protamine.

Inorganic ion receptor activities are those processes brought about as a result of inorganic ion receptor activation. Such processes include the production of molecules which can act as intracellular or extracellular
5 messengers.

Inorganic ion receptor-modulating agents include ionomimetics, ionolytics, calcimimetics, and calcilytics. Ionomimetics are molecules which bind to an inorganic ion receptor and mimics (*i.e.*, evokes or potentiates) the effects
10 of an inorganic ion at an inorganic ion receptor. Preferably, the molecule affects one or more calcium receptor activities. Calcimimetics are ionomimetics which affect one or more calcium receptor activities and bind to a calcium receptor.

15 Ionolytics are molecules which bind to a inorganic ion receptor and block (*i.e.*, inhibits or diminishes) one or more activities caused by an inorganic ion on an inorganic ion receptor. Preferably, the molecule affects one or more calcium receptor activities. Calcilytics are ionolytics
20 which inhibit one or more calcium receptor activities evoked by extracellular calcium and bind to a calcium receptor.

Ionomimetics and ionolytics may bind at the same receptor site as the native inorganic ion ligand binds or can bind at a different site (*e.g.*, allosteric site). For
25 example, NPS R-467 binding to a calcium receptor results in calcium receptor activity and, thus, NPS R-467 is classified as a calcimimetic. However, NPS R-467 binds to the calcium receptor at a different site (*i.e.*, an allosteric site) than extracellular calcium.

30 The EC_{50} is the concentration of agent which causes a half maximal mimicking effect. For example, the EC_{50} for calcium receptor activities can be determined by assaying one or more of the activities of extracellular calcium at a calcium receptor. Examples of suitable assays for measuring

EC₅₀ are described herein and include oocyte expression assays and measuring increases in intracellular calcium due to calcium receptor activity. Preferably, such assays measure the release or inhibition of a particular hormone associated with activity of a calcium receptor.

An inorganic ion receptor-modulating agent preferably selectively targets inorganic ion receptor activity in a particular cell. For example, selective targeting of a calcium receptor activity is achieved by an agent exerting a greater effect on a calcium receptor activity in one cell type than at another cell type for a given concentration of agent. Preferably, the differential effect is 10-fold or greater as measured *in vivo* or *in vitro*. More preferably, the differential effect is measured *in vivo* and the agent concentration is measured as the plasma concentration or extracellular fluid concentration and the measured effect is the production of extracellular messengers such as plasma calcitonin, parathyroid hormone, or plasma calcium. For example, in a preferred embodiment, the agent selectively targets PTH secretion over calcitonin secretion.

In one embodiment concerning the structure of the inorganic ion receptor-modulating agent, the molecule is positively charged at physiological pH, and is selected from the group consisting of branched or cyclic polyamines, positively charged polyamino acids, and arylalkylamines. Preferably, the branched polyamine has the formula $H_2N-(CH_2)_j-(NR_i-(CH_2)_j)_k-NH_2$ where k is an integer from 1 to 10, each j is the same or different and is an integer from 2 to 20, and each R_i is the same or different and is selected from the group consisting of hydrogen and $-(CH_2)_j-NH_2$, where j is as defined above, and at least one R_i is not hydrogen. Preferably, the inorganic ion receptor-modulating agent can modulate one or more calcium receptor activities.

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$$\begin{array}{c} X_m - (Ar \text{ or } R) \\ X_m - (Ar \text{ or } R) \end{array} \begin{array}{c} \diagup \\ \diagdown \end{array} Y - Z - N \begin{array}{c} R \\ \mid \\ (Ar \text{ or } R) - X_m \\ \mid \\ (R \text{ or } X) \\ \mid \\ (R \text{ or } X) \end{array}$$

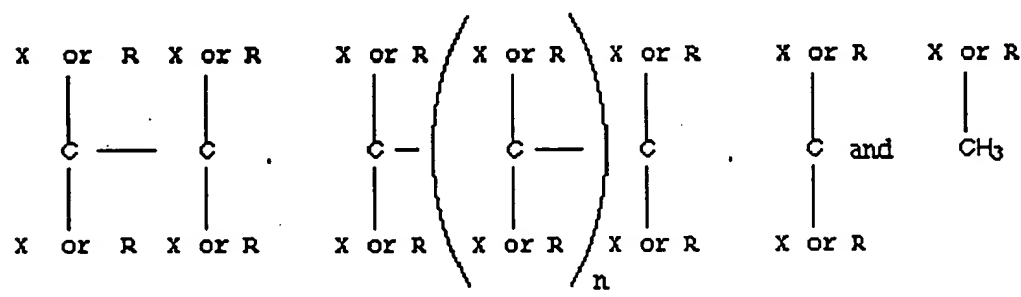
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each R independently is selected from the group consisting of hydrogen, methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, cyclopentyl, cyclohexyl, cycloheptyl, cyclooctyl, indenyl, indanyl, dihydroindolyl, tetrahydroindolyl, and 2-, 3-, or 4- piperid(in)yl;

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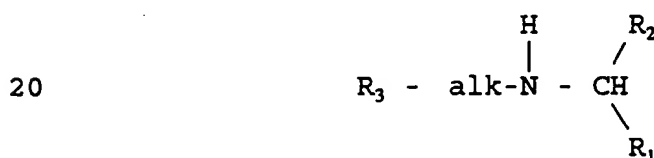
where each n is independently between 1 and 4 inclusive;
and

each m is independently between 0 and 5 inclusive.

A hydrophobic entity refers to a non-polar group or
5 moiety such as an aromatic or a cycloaliphatic ring or ring
system. Preferably, the hydrophobic entity is selected from
the group consisting of phenyl, cyclohexyl, 2-, 3-, or 4-
pyridyl, 1- or 2-naphthyl, α - or β -tetrahydronaphthyl, 1- or
2-quinolinyl, 2- or 3-indolyl, benzyl, and phenoxy.

10 More preferably, the inorganic ion receptor-modulating
agent is a substituted R-phenylpropyl- α -phenethylamine,
substituted R-benzyl- α -1-naphthylethylamine analogues, and
derivatives having the formula:

15 STRUCTURE III



where alk is straight- or branched-chain alkylene of
25 from 0 to 6 carbon atoms;

R_1 is lower alkyl of from 1 to 3 carbon atoms or lower
haloalkyl of from 1 to 3 carbon atoms substituted with from
1 to 7 halogen atoms;

R_2 and R_3 are independently selected carbocyclic aryl or
30 cycloalkyl groups, either monocyclic or bicyclic, having 5-
to 7-membered rings optionally substituted with 1 to 5
substituents independently selected from lower alkyl of 1 to
3 carbon atoms, lower haloalkyl of 1 to 3 carbon atoms
substituted with 1 to 7 halogen atoms, lower alkoxy of 1 to
35 3 carbon atoms, halogen, nitro, amino, alkylamino, amido,
lower alkylamido of 1 to 3 carbon atoms, cyano, hydroxy, acyl
of 2 to 4 carbon atoms, lower hydroxyalkyl of 1 to 3 carbon

atoms or lower thioalkyl of 1 to 3 carbon atoms. Suitable carbocyclic aryl groups are groups having one or two rings, at least one of which has aromatic character and include carbocyclic aryl groups such as phenyl and bicyclic carbocyclic aryl groups such as naphthyl.

Preferred compounds include those where alk is n-propylene, methylene, or R-methyl methinyl. Also preferred are compounds where R₁ is R-methyl. Also preferred are those compounds where R₂ and R₃ are optionally substituted phenyl or naphthyl.

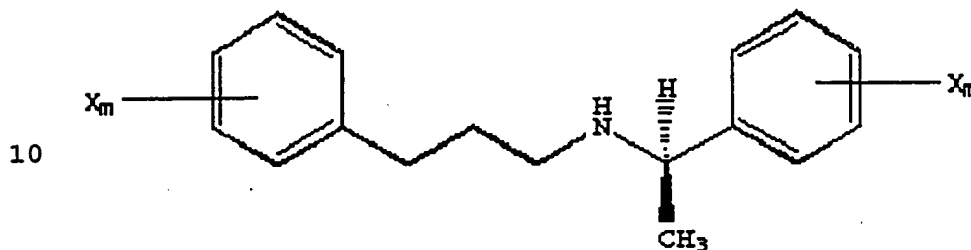
More preferred compounds are those where R₂ is monosubstituted phenyl, more preferably meta-substituted; or 1-naphthyl. More preferred R₃ groups are unsubstituted or monosubstituted phenyl, especially meta- or ortho-substituted, or 2-naphthyl. Preferred substituents for R₂ are halogen, haloalkyl, preferably trihalomethyl, alkoxy, preferably methoxy, and thioalkyl, preferably thiomethyl. Preferred substituents for R₃ are meta- or ortho-halogen, preferably chlorine, fluorine, or CF₃, and para- or ortho-alkoxy, preferably methoxy, and meta-lower alkyl, preferably methyl.

As is apparent from the above formula, preparation of the molecules may result in racemic mixtures containing individual stereoisomers. More preferred compounds are R-phenylpropyl- α -phenethylamine and R-benzyl- α -1-naphthylethylamine derivatives which are believed to exhibit enhanced activity in lowering serum ionized calcium.

More preferably, the molecule is a substituted *R*-phenylpropyl- α -phenethylamine derivative, or a substituted *R*-benzyl- α -phenethylamine derivative, having the structure:

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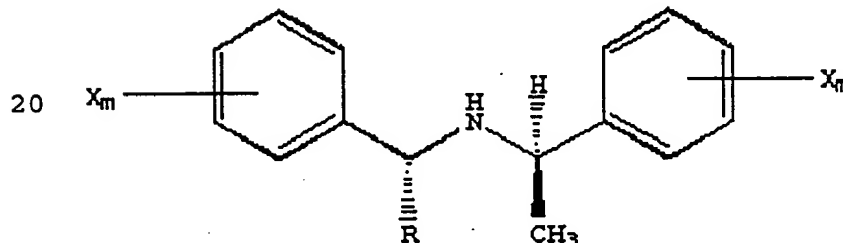
STRUCTURE IV



or

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STRUCTURE V



where each X is preferably independently selected from the group consisting of Cl, F, I, CF₃, CH₃, isopropyl, CH₃O, CH₃S, CF₃O, CF₃CH₂O, an aliphatic ring and an attached or fused, preferably fused aromatic ring. Preferably, the aromatic and aliphatic rings have 5 to 7 members. More preferably, the aromatic and aliphatic rings contain only carbon atoms (i.e., the ring is not a heterocyclic ring); and R is preferably H, CH₃, ethyl, or isopropyl.

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In more preferred embodiments the molecule inhibits parathyroid hormone secretion from a parathyroid cell; inhibits bone resorption *in vivo* by an osteoclast; inhibits bone resorption *in vitro* by an osteoclast; stimulates
5 calcitonin secretion *in vitro* or *in vivo* from a c-cell; or the molecule evokes the mobilization of intracellular Ca^{2+} to cause an increase in $[\text{Ca}^{2+}]_i$.

Preferably, the molecule is either a calcimimetic or calcilytic having an EC_{50} or IC_{50} at a calcium receptor of less
10 than or equal to 5 μM , and even more preferably less than or equal to 1 μM , 100 nmolar, 10 nmolar, or 1 nmolar. Such lower EC_{50} 's or IC_{50} 's are advantageous since they allow lower concentrations of molecules to be used *in vivo* or *in vitro* for therapy or diagnosis. The discovery of molecules with
15 such low EC_{50} 's and IC_{50} 's enables the design and synthesis of additional molecules having similar or improved potency, effectiveness, and/or selectivity.

In another preferred embodiment, the molecule has an EC_{50} or IC_{50} less than or equal to 5 μM at one or more, but not all
20 cells chosen from the group consisting: of parathyroid cell, bone osteoclast, juxtaglomerular kidney cell, proximal tubule kidney cell, distal tubule kidney cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct,
25 keratinocyte in the epidermis, parafollicular cell in the thyroid (C-cell), intestinal cell, trophoblast in the placenta, platelet, vascular smooth muscle cell, cardiac atrial cell, gastrin-secreting cell, glucagon-secreting cell, kidney mesangial cell, mammary cell, beta cell, fat/adipose
30 cell, immune cell, GI tract cell, skin cell, adrenal cell, pituitary cell, hypothalamic cell and cell of the subfornical organ.

More preferably, the cells are chosen from the group consisting of parathyroid cell, central nervous system cell,

peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct in the kidney, parafollicular cell in the thyroid (C-cell), intestinal cell, GI tract cell, pituitary cell, hypothalamic cell and cell of
5 the subfornical organ. This presence of a calcium receptor in this group of cells has been confirmed by physical data such as *in situ* hybridization and antibody staining.

Another aspect of the present invention features a calcium receptor-modulating agent comprising a molecule
10 selected from the group consisting of: NPS R-467, NPS R-568, compound 1D, compound 3U, compound 3V, compound 4A, compound 4B, compound 4C, compound 4D, compound 4G, compound 4H, compound 4J, compound 4M, compound 4N, compound 4P, compound 4R/6V, compound 4S, compound 4T/4U, compound 4V, compound 4W,
15 compound 4Y, compound 4Z/5A, compound 5B/5C, compound 5W/5Y, compound 6E, compound 6F, compound 6R, compound 6T, compound 6X, compound 7W, compound 7X, compound 8D, compound 8J, compound 8K, compound 8R, compound 8S, compound 8T, compound 8U, compound 8X, compound 8Z, compound 9C, compound 9D,
20 compound 9R, compound 9S, compound 10F, compound 11D, compound 11X, compound 11Y, compound 12L, compound 12U, compound 12V, compound 12W, compound 12Y, compound 13Q, compound 13R, compound 13S, compound 13U, compound 13X, compound 14L, compound 14Q, compound 14U, compound 14V,
25 compound 14Y, compound 15G, compound 16Q, compound 16R, compound 16T, compound 16V, compound 16W, compound 16X, compound 17M, compound 17O, compound 17P, compound 17R, compound 17W, compound 17X, compound 20F, compound 20I, compound 20J, compound 20R, compound 20S, compound 21D,
30 compound 21F, compound 21G, compound 21O, compound 21P, compound 21Q, and compound 21R (see Figure 36).

Another aspect of the present invention features a pharmaceutical composition made up of an inorganic ion receptor-modulating agent and a physiologically acceptable

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carrier. Such agents can be used to treat patients by modulating inorganic ion receptor activity.

Prior to this invention, applicant was unaware of any agent acting on the calcium receptor useful in the treatment of diseases caused by irregularity in operation or regulation of a calcium receptor or in diseases in an animal having normal calcium receptors, but which can be treated by modulating calcium activity.

A pharmacological agent or composition refers to an agent or composition in a form suitable for administration into a mammal, preferably a human. Considerations concerning forms suitable for administration are known in the art and include toxic effects, solubility, route of administration, and maintaining activity. For example, pharmacological agents or compositions injected into the blood stream should be soluble.

Pharmaceutical compositions can also be formulated as pharmaceutically acceptable salts (e.g., acid addition salts) and complexes thereof. The preparation of such salts can facilitate the pharmacological use of an agent by altering its physical characteristics without preventing it from exerting a physiological effect.

Another aspect of the present invention features a method for modulating inorganic ion receptor activity, preferably calcium receptor activity. The method involves the step of providing to a cell comprising an inorganic ion receptor an amount of an inorganic ion receptor-modulating molecule sufficient to either mimic one or more effects of an inorganic ion at the inorganic ion receptor, or block one or more effects of the inorganic ion at the inorganic ion receptor. The method can be carried out *in vitro* or *in vivo*.

Preferably, the molecule is either a calcimimetic or a calcilytic which modulates one or more calcium receptor activity. Examples of calcium receptor-modulating molecules

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or agents are described herein. Additional calcium receptor-modulating agents can be obtained based on the present disclosure. More preferably, the method is carried out *in vivo* to treat a patient.

5 Another aspect the present invention features a method for treating a patient by modulating inorganic ion receptor activity. The method involves administering to the patient a therapeutically effective amount of an inorganic ion receptor-modulating agent.

10 In a preferred embodiment, the disease or disorder is treated by modulating calcium receptor activity by administering to the patient a therapeutically effective amount of a calcium receptor-modulating agent.

Preferably the disease or disorder is characterized by
15 one or more of the following: (1) abnormal inorganic ion homeostasis, more preferably abnormal calcium homeostasis; (2) an abnormal level of a messenger whose production or secretion is affected by inorganic ion receptor activity, more preferably affected by calcium receptor activity; and
20 (3) an abnormal level or activity of a messenger whose function is affected by inorganic ion receptor activity, more preferably affected by calcium receptor activity.

Diseases characterized by abnormal calcium homeostasis include hyperparathyroidism, osteoporosis and other bone and
25 mineral-related disorders, and the like (as described, e.g., in standard medical text books, such as "Harrison's Principles of Internal Medicine"). Such diseases are treated using calcium receptor-modulating agents which mimic or block one or more of the effects of extracellular Ca^{2+} on a calcium
30 receptor and, thereby, directly or indirectly affect the levels of proteins or other molecules in the body of the patient.

By "therapeutically effective amount" is meant an amount of an agent which relieves to some extent one or more

5 In a preferred embodiment, the patient has a disease or disorder characterized by an abnormal level of one or more calcium receptor-regulated components and the molecule is active on a calcium receptor of a cell selected from the group consisting of: parathyroid cell, bone osteoclast, 10 juxtaglomerular kidney cell, proximal tubule kidney cell, distal tubule kidney cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct, keratinocyte in the epidermis, parafollicular cell in the thyroid (C-cell), 15 intestinal cell, trophoblast in the placenta, platelet, vascular smooth muscle cell, cardiac atrial cell, gastrin-secreting cell, glucagon-secreting cell, kidney mesangial cell, mammary cell, beta cell, fat/adipose cell, immune cell, GI tract cell, skin cell, adrenal cell, pituitary cell, 20 hypothalamic cell and cell of the subfornical organ.

In a preferred embodiment, the agent is a calcimimetic acting on a parathyroid cell calcium receptor and reduces the level of parathyroid hormone in the serum of the patient. More preferably, the level is reduced to a degree sufficient to cause a decrease in plasma Ca^{2+} . Most preferably, the parathyroid hormone level is reduced to that present in a normal individual.

In another preferred embodiment, the agent is a calcilytic acting on a parathyroid cell calcium receptor and increases the level of parathyroid hormone in the serum of the patient. More preferably, the level is increased to a degree sufficient to cause an increase in bone mineral density of a patient.

In another aspect, the invention features a method for diagnosing a disease or disorder in a patient characterized by an abnormal number of inorganic ion receptors, or an altered inorganic ion receptors. The method involves identifying the number and/or location and/or functional integrity of one or more inorganic ion receptor. The number and/or location and/or functional integrity is compared with that observed in patients characterized as normal or diseased as an indication of the presence of the disease or disorder.

Diagnoses can be carried out using inorganic ion receptor-binding agents. For example, calcium receptor-modulating agents binding to calcium receptors, and antibodies which bind to calcium receptors, can be used for diagnoses. Preferably, binding agents are labeled with a detectable moiety, such as a radioisotope or alkaline phosphatase.

An altered receptor has a different structure than the receptor has in normal individuals and is associated with a disease or disorder involving an inorganic ion receptor. Such alterations may affect receptor function, and can be detected by assaying for a structural difference between the altered and normal receptor. Binding agents which bind to an altered receptor, but not to a normal receptor, can be used to determine the presence of an altered receptor. Additionally, a binding agent which can bind to a normal receptor, but not to a particular altered receptor, can be used to determine the presence of the particular altered receptor.

Similarly, the number of receptors can be determined by using agents binding to the tested-for receptor. Such assays generally involve using a labeled binding agent and can be carried out using standard formats such as competitive, non-competitive, homogenous, and heterogenous assays.

In other preferred embodiments, the method is an immunoassay in which an antibody to a calcium receptor is used to identify the number and/or location and/or functional integrity of the calcium receptors; the assay involves providing a labeled calcimimetic or calcilytic molecule; the presence of a cancer, e.g., an ectopic tumor of the parathyroid, is tested for by measuring calcium receptor number or alteration; and conditions characterized by an above-normal number of osteoclasts in bone or an increased level of activity of osteoclasts in bone is tested for by measuring the number of calcium receptors.

In another aspect, the invention features a method for identifying a molecule useful as a therapeutic molecule to modulate inorganic ion receptor activity or as a diagnostic agent to diagnose patients suffering from a disease characterized by an abnormal inorganic ion activity. Preferably, the method is used to identify calcimimetics or calcilytics by screening potentially useful molecules for an ability to mimic or block an activity of extracellular Ca^{2+} on a cell having a calcium receptor and determining whether the molecule has an EC_{50} or IC_{50} of less than or equal to $5 \mu\text{M}$. More preferably, the molecule is tested for its ability to mimic or block an increase in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} .

Identification of inorganic ion receptor-modulating agents is facilitated by using a high-throughput screening system. High-throughput screening allows a large number of molecules to be tested. For example, a large number of molecules can be tested individually using rapid automated

techniques or in combination using a combinational library. Individual compounds able to modulate inorganic ion receptor activity present in a combinational library can be obtained by purifying and retesting fractions of the combinational
5 library. Thus, thousands to millions of molecules can be screened in a single day.

Active molecules can be used as models to design additional molecules having equivalent or increased activity. Preferably, the identification method uses a recombinant
10 inorganic ion receptor, more preferably a recombinant calcium receptor. Recombinant receptors can be introduced into different cells using a vector encoding the receptor.

Preferably, the activity of molecules in different cells is tested to identify a calcimimetic or calcilytic molecule
15 which mimics or blocks one or more activities of Ca^{2+} at a first type of calcium receptor, but not at a second type of calcium receptor.

Another aspect of the present invention features a purified nucleic acid containing at least 12 contiguous
20 nucleotides of a nucleic acid sequence provide in SEQ. ID. NO. 1, SEQ. ID. NO. 2, SEQ. ID. NO. 3 or SEQ. ID. NO. 4. By "purified" in reference to nucleic acid is meant the nucleic acid is present in a form (*i.e.*, its association with other molecules) other than found in nature. For example, purified
25 receptor nucleic acid is separated from one or more nucleic acids which are present on the same chromosome. Preferably, the purified nucleic acid is separated from at least 90% of the other nucleic acids present on the same chromosome.

Another example of purified nucleic acid is recombinant
30 nucleic acid. Preferably, recombinant nucleic acid contains nucleic acid encoding an inorganic ion receptor or receptor fragment cloned in an expression vector. An expression vector contains the necessary elements for expressing a cloned nucleic acid sequence to produce a polypeptides. An

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expression vector contains a promoter region (which directs the initiation of RNA transcription) as well as the DNA sequences which, when transcribed into RNA, will signal synthesis initiation.

- 5 Recombinant nucleic acid may contain nucleic acid encoding for an inorganic ion receptor, receptor fragment, or inorganic ion receptor derivative, under the control of its genomic regulatory elements, or under the control of exogenous regulatory elements including an exogenous
10 promoter. By "exogenous" is meant a promoter that is not normally coupled *in vivo* transcriptionally to the coding sequence for the inorganic ion receptor. Preferably, the nucleic acid is provided as a substantially purified preparation representing at least 75%, more preferably 85%,
15 most preferably 95% of the total nucleic acids present in the preparation.

- Nucleic acid sequences provided in SEQ. ID. NO. 1, SEQ. ID. NO. 2, SEQ. ID. NO. 3, and SEQ. ID. NO. 4 each encode for a calcium receptor. Nucleic acid sequences encoding both
20 full length calcium receptors, calcium receptor fragments, derivatives of full length calcium receptors, and derivatives of calcium receptor fragments are useful in the present invention.

- Uses of nucleic acids encoding cloned receptors or
25 receptor fragments include one or more the following: (1) producing receptor proteins which can be used, for example, for structure determination, to assay a molecule's activity on a receptor, and to obtain antibodies binding to the receptor; (2) being sequenced to determine a receptor's
30 nucleotide sequence which can be used, for example, as a basis for comparison with other receptors to determine conserved regions, determine unique nucleotide sequences for normal and altered receptors, and to determine nucleotide sequences to be used as target sites for antisense nucleic

acids, ribozymes, hybridization detection probes, or PCR amplification primers; (3) as hybridization detection probes to detect the presence of a native receptor and/or a related receptor in a sample; and (4) as PCR primers to generate particular nucleic acid sequence regions, for example to generate regions to be probed by hybridization detection probes.

Preferably, the nucleic acid contains at least 14, more preferably at least 20, more preferably at least 27, and most preferably at least 45, contiguous nucleic acids of a sequence provided in SEQ. ID. NO. 1, SEQ. ID. NO. 2, SEQ. ID. NO. 3, or SEQ. ID. NO. 4. Advantages of longer-length nucleic acid include producing longer-length protein fragments having the sequence of a calcium receptor which can be used, for example, to produce antibodies; increased nucleic acid probe specificity under higher stringent hybridization assay conditions; and more specificity for related inorganic ion receptor nucleic acid under lower stringency hybridization assay conditions.

Another aspect of the present invention features a purified nucleic acid encoding an inorganic ion receptor or fragment thereof. The nucleic acid encodes at least 6 contiguous amino acids provided in SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8. Due to the degeneracy of the genetic code, different combinations of nucleotides can code for the same polypeptide. Thus, numerous inorganic ion receptors and receptor fragments having the same amino acid sequences can be encoded for by different nucleic acid sequences. In preferred embodiments, the nucleic acid encodes at least 12, at least 18, or at least 54 contiguous amino acids of SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8.

Another aspect of the present invention features a purified nucleic acid having a nucleic acid sequence region

of at least 12 contiguous nucleotides substantially complementary to a sequence region in SEQ. ID. NO. 1, SEQ. ID. NO. 2, SEQ. ID. NO. 3 or SEQ. ID. NO. 4. By "substantially complementary" is meant that the purified
5 nucleic acid can hybridize to the complementary sequence region in nucleic acid encoded by SEQ. ID. NO. 1, SEQ. ID. NO. 2, SEQ. ID. NO. 3 or SEQ. ID. NO. 4 under stringent hybridizing conditions. Such nucleic acid sequences are particularly useful as hybridization detection probes to
10 detect the presence of nucleic acid encoding a particular receptor. Under stringent hybridization conditions, only highly complementary nucleic acid sequences hybridize. Preferably, such conditions prevent hybridization of nucleic acids having 4 mismatches out of 20 contiguous nucleotides,
15 more preferably 2 mismatches out of 20 contiguous nucleotides, most preferably one mismatch out of 20 contiguous nucleotides. In preferred embodiments, the nucleic acid is substantially complementary to at least 20, at least 27, or at least 45, contiguous nucleotides provided
20 in SEQ. ID. NO. 1, SEQ. ID. NO. 2, SEQ. ID. NO. 3, or SEQ. ID. NO. 4.

Another aspect of the present invention features a purified polypeptide having at least 6 contiguous amino acids of an amino acid sequence provided in SEQ. ID. NO. 5, SEQ.
25 ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8. By "purified" in reference to a polypeptide is meant that the polypeptide is in a form (i.e., its association with other molecules) distinct from naturally occurring polypeptide. Preferably, the polypeptide is provided as a substantially purified
30 preparation representing at least 75%, more preferably 85%, most preferably 95% of the total protein in the preparation. In preferred embodiments, the purified polypeptide has at least 12, 18, or 54 contiguous amino acids of SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8.

Preferred receptor fragments include those having functional receptor activity, a binding site, epitope for antibody recognition (typically at six amino acids), and/or a site which binds a calcimimetic or calcilytic. Other preferred receptor fragments include those having only an extracellular portion, a transmembrane portion, an intracellular portion, and/or a multiple transmembrane portion (e.g., seven transmembrane portion). Such receptor fragments have various uses such as being used to obtain antibodies to a particular region and being used to form chimeric receptors with fragments of other receptors to create a new receptor having unique properties.

The invention also features derivatives of full-length inorganic ion receptors and fragments thereof having the same, or substantially the same, activity as the full-length parent inorganic ion receptor or fragment. Such derivatives include amino acid addition(s), substitution(s), and deletion(s) to the receptor which do not prevent the derivative receptor from carrying out one or more of the activities of the parent receptor.

Another aspect of the present invention features a recombinant cell or tissue. The recombinant cell or tissue is made up of a recombined nucleic acid sequence encoding at least 6 contiguous amino acids provided in SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8 and a cell able to express the nucleic acid. Recombinant cells have various uses including acting as biological factories to produce polypeptides encoded for by the recombinant nucleic acid, and for producing cells containing a functioning calcium receptor. Cells containing a functioning calcium receptor can be used, for example, to screen for calcimimetics or calcilytics.

In preferred embodiments, the recombinant nucleic acid encodes a functioning calcium receptor, more preferably a

human calcium receptor; the cell or tissue is selected from the group consisting of: parathyroid cell, bone osteoclast, juxtaglomerular kidney cell, proximal tubule kidney cell, distal tubule kidney cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct, keratinocyte in the epidermis, parafollicular cell in the thyroid (C-cell), intestinal cell, trophoblast in the placenta, platelet, vascular smooth muscle cell, cardiac atrial cell, gastrin-secreting cell, glucagon-secreting cell, kidney mesangial cell, mammary cell, beta cell, fat/adipose cell, immune cell, GI tract cell, skin cell, adrenal cell, pituitary cell, hypothalamic cell and cell of the subfornical organ; and the recombinant nucleic acid encodes at least 12, 18 or 54 contiguous amino acids of SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8.

Another aspect of the present invention features a calcium receptor-binding agent able to bind a polypeptide having an amino acid sequence of SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8. The binding agent is preferably a purified antibody which recognizes an epitope present on a polypeptide having an amino acid sequence of SEQ. ID. NO. 5, SEQ. ID. NO. 6, SEQ. ID. NO. 7 or SEQ. ID. NO. 8. Other binding agents include molecules which bind to the receptor, for example, calcimimetics and calcilytics binding to the calcium receptor.

By "purified" in reference to an antibody is meant that the antibody is in a form (i.e., its association with other molecules) distinct from naturally occurring antibody, such as in a purified form. Preferably, the antibody is provided as a purified preparation representing at least 1%, more preferably at least 50%, more preferably at least 85%, most preferably at least 95% of the total protein in the preparation.

Antibodies able to bind inorganic ion receptors have various uses such as being used as therapeutic agents to modulate calcium receptor activity; as diagnostic tools for determining calcium receptor number and/or location and/or functional integrity to diagnose a Ca^{2+} -related disease; and as research tools for studying receptor synthesis, structure, and function. For example, antibodies targeted to the calcium receptor are useful to elucidate which portion of the receptor a particular molecule such as the natural ligand, a calcimimetic, or calcilytic, binds.

In preferred embodiments, the binding agent binds to an extracellular region of a calcium receptor and the binding agent binds to a calcium receptor expressed in tissue or cells selected from the group consisting of: parathyroid cell, bone osteoclast, juxtaglomerular kidney cell, proximal tubule kidney cell, distal tubule kidney cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct, keratinocyte in the epidermis, parafollicular cell in the thyroid (C-cell), intestinal cell, trophoblast in the placenta, platelet, vascular smooth muscle cell, cardiac atrial cell, gastrin-secreting cell, glucagon-secreting cell, kidney mesangial cell, mammary cell, beta cell, fat/adipose cell, immune cell, GI tract cell, skin cell, adrenal cell, pituitary cell, hypothalamic cell and cell of the subfornical organ. More preferably, the cells are chosen from the group consisting of parathyroid cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct in the kidney, parafollicular cell in the thyroid (C-cell), intestinal cell, GI tract cell, pituitary cell, hypothalamic cell and cell of the subfornical organ.

In other preferred embodiments, the binding agent is coupled to a toxin. Binding agents coupled to a toxin can be

used to deliver the toxin to a cell containing a particular receptor. For example, an antibody coupled to a toxin directed to a cancer cell characterized by an abnormal receptor can selectively kill the cancer cell.

5 In other aspects, the invention provides transgenic, nonhuman mammals containing a transgene encoding an inorganic ion receptor or a gene affecting the expression of an inorganic ion receptor and methods of creating a transgenic nonhuman mammal containing a transgene encoding an inorganic
10 ion receptor. Preferably, these aspects use a calcium receptor.

Transgenic nonhuman mammals are particularly useful as an *in vivo* test system for studying the effects of introducing an inorganic ion receptor, preferably a calcium
15 receptor; regulating the expression of an inorganic ion receptor, preferably a calcium receptor (*i.e.*, through the introduction of additional genes, antisense nucleic acids, or ribozymes); and studying the effect of molecules which mimic or block the effect of inorganic ions on an inorganic ion
20 receptor, preferably mimic or block the effect of calcium on a calcium receptor. In preferred embodiments, the transgene encodes a calcium receptor; alters the expression of a calcium receptor; inactivates the expression of the inorganic ion receptor, preferably a calcium receptor; and up-regulates
25 or down-regulates the expression of the inorganic ion receptor, preferably a calcium receptor.

Another aspect of the present invention features a method for treating a patient by administering a therapeutically effective amount of nucleic acid encoding a
30 functioning inorganic ion receptor. Preferably, nucleic acid encoding a functioning calcium receptor is administered to a patient having a disease or disorder characterized by one or more of the following: (1) abnormal calcium homeostasis; (2) an abnormal level of a messenger whose production or

secretion is affected by calcium receptor activity; and (3) an abnormal level or activity of a messenger whose function is affected by calcium receptor activity. The nucleic acid can be administered using standard techniques such through
5 the use of retroviral vectors and liposomes.

Another aspect of the present invention features a method for treating a patient by administering a therapeutically effective amount of a nucleic acid which inhibits expression of an inorganic ion receptor.
10 Preferably, the administered nucleic acid inhibits expression of a calcium receptor and the disease or disorder is characterized by one or more of the following: (1) abnormal calcium homeostasis; (2) an abnormal level of a messenger whose production or secretion is affected by calcium receptor
15 activity; and (3) an abnormal level or activity of a messenger whose function is affected by calcium receptor activity.

Nucleic acids able to inhibit expression of an inorganic ion receptor include anti-sense oligonucleotides, ribozymes
20 and nucleic acid able to combine through homologous recombination with an endogenous gene encoding the receptor. Target sites of inhibitory nucleic acid include promoters, other regulatory agents acting on promoters, mRNA, pre-processed mRNA, and genomic DNA. Administration can be
25 carried out by providing a transgene encoding the agent or by any other suitable method depending upon the use to which the particular method is directed.

Another aspect of the present invention features a method for identifying an inorganic ion receptor-modulating
30 agent. The method involves contacting a cell containing a recombinant nucleic acid encoding an inorganic ion receptor with the agent and detecting a change in inorganic ion receptor activity. Preferably, the method is used to identify a calcium receptor-modulating agent.

Thus, the present invention features agents and methods useful in the diagnosis and treatment of a variety of diseases and disorders by targeting inorganic ion receptor activity. For example, molecules mimicking external calcium may be used to selectively depress secretion of parathyroid hormone from parathyroid cells, or depress bone resorption by osteoclasts, or stimulate secretion of calcitonin from C-cells. Such molecules can be used to treat diseases characterized by abnormal calcium homeostasis such as hyperparathyroidism and osteoporosis.

Other features and advantages of the invention will be apparent from the following description of the preferred embodiments thereof and from the claims.

15 BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1a-1f depict representative molecules useful in the invention.

Fig. 2 is a graphical representation showing increases in $[Ca^{2+}]_i$ induced by extracellular Ca^{2+} in quin-2- or fura-2-loaded bovine parathyroid cells. The initial $[Ca^{2+}]_i$ was 0.5 mM (using $CaCl_2$) and, at each of the arrows, was increased in 0.5 mM increments.

Figs. 3a-3c are graphical representations showing mobilization of $[Ca^{2+}]_i$ in bovine parathyroid cells. The initial $[Ca^{2+}]_i$ was 0.5 mM and was decreased to $< 1 \mu M$ by the addition of EGTA as indicated. (a) Extracellular Mg^{2+} (8 mM final) elicits an increase in $[Ca^{2+}]_i$ in the absence of extracellular Ca^{2+} . (b) Pretreatment with ionomycin ($1 \mu M$) blocks the response to Mg^{2+} . (c) Pretreatment with 5 μM molecule 1799 (a mitochondrial uncoupler) is without effect on the response to Mg^{2+} .

Figs. 4a-4c are graphical representations showing preferential inhibitory effects of a low concentration of Gd^{3+} on steady-state increases in $[Ca^{2+}]_i$ and that a high

concentration of Gd^{3+} elicits a transient increase in $[Ca^{2+}]_i$ in bovine parathyroid cells. Top panel: Control. Initial concentration of extracellular Ca^{2+} was 0.5 mM and was increased by 0.5 mM at each of the arrowheads. Middle panel: Gd^{3+} (5 μM) blocks steady-state, but not transient increases in $[Ca^{2+}]_i$ elicited by extracellular Ca^{2+} . Lower panel: Gd^{3+} (50 μM) elicits a transient increase in $[Ca^{2+}]_i$ and abolishes both transient and sustained responses to extracellular Ca^{2+} . In the middle and lower panels, just enough EGTA was added to chelate preferentially Gd^{3+} : the block of Ca^{2+} influx is removed and $[Ca^{2+}]_i$ rises promptly.

Figs. 5a-5c are graphical representations showing that the effects of phorbol myristate acetate (PMA) on $[Ca^{2+}]_i$, IP_3 formation, and PTH secretion are overcome by increasing concentrations of extracellular Ca^{2+} in bovine parathyroid cells. For each variable, there is a shift to the right in the concentration-response curve for extracellular Ca^{2+} . The concentration-response curves vary sigmoidally as $[Ca^{2+}]$ increases linearly. The open circles refer to no PMA. The closed circles refer to 100 nM PMA.

Fig. 6 is a graphical representation showing that increases in $[Ca^{2+}]_i$ elicited by spermine are progressively depressed by increasing $[Ca^{2+}]$ in bovine parathyroid cells. Spermine (200 μM) was added at the time shown by arrowheads. In this and all subsequent figures, the numbers accompanying the traces are $[Ca^{2+}]_i$ in nM.

Fig. 7 is a graphical representation showing that spermine mobilizes intracellular Ca^{2+} in bovine parathyroid cells. EGTA was added to reduce $[Ca^{2+}]$ to $<1 \mu M$ before the addition of spermine (200 μM) as indicated (left trace). Pretreatment with ionomycin (1 μM) blocks the response to spermine (right trace).

Figs. 8a and 8b are graphical representations showing that spermine increases $[Ca^{2+}]_i$ and inhibits PTH secretion in

bovine parathyroid cells similarly to extracellular Ca^{2+} . The data points for the spermine dose concentration-response curves are the means of two experiments.

Figs. 9a-9c are graphical representations showing the contrasting effects of PMA on responses to extracellular Ca^{2+} and on responses to $\text{ATP}\gamma\text{S}$ in bovine parathyroid cells. Left panel: The concentration-response curve for extracellular Ca^{2+} -induced inhibition of cyclic AMP formation is shifted to the right by PMA (100 nM). Middle panel: PMA does not affect the ability of $\text{ATP}\gamma\text{S}$ to increase $[\text{Ca}^{2+}]_i$. The concentration-response curve to $\text{ATP}\gamma\text{S}$ shows classical sigmoidal behavior as a function of the log concentration, in contrast to extracellular divalent cations.

Figs. 10a-10c are graphical representations showing mobilization of intracellular Ca^{2+} in human parathyroid cells evoked by extracellular Mg^{2+} . Cells were obtained from an adenoma and bathed in buffer containing 0.5 mM extracellular Ca^{2+} . (a) Transient and sustained increases in $[\text{Ca}^{2+}]_i$ elicited by extracellular Mg^{2+} (10 mM, final) shows that sustained increases are not affected by nimodipine (1 μM) but are depressed by La^{3+} (1 μM) and return promptly when La^{3+} is selectively chelated by a low concentration of EGTA (50 μM). (b) La^{3+} (1 μM) blocks the sustained, but not the transient increase in $[\text{Ca}^{2+}]_i$ elicited by extracellular Mg^{2+} . (c) Cytosolic Ca^{2+} transients elicited by extracellular Mg^{2+} persist in the absence of extracellular Ca^{2+} .

Figs. 11a-11i are graphical representations showing mobilization of intracellular Ca^{2+} evoked by neomycin or protamine in bovine parathyroid cells. In all traces, the initial $[\text{Ca}^{2+}]$ and $[\text{Mg}^{2+}]$ was 0.5 and 1 mM, respectively. In traces (a) and (b), the Ca^{2+} and Mg^{2+} concentrations were increased to 2 and 8 mM, from 0.5 and 1 mM, respectively. In the other traces, (c) through (i) neomycin B (30 μM) or protamine (1 $\mu\text{g/ml}$) were added as indicated. La^{3+} (1 μM),

EGTA (1 mM), or ionomycin (100 nM) were added as indicated. Each trace is representative of the pattern seen in 5 or more trials using at least 3 different cell preparations. Bar = 1 minute.

5 Fig. 12 is a graphical representation showing that neomycin B blocks transient, but does not block steady-state increases in $[Ca^{2+}]_i$ elicited by extracellular Ca^{2+} in bovine parathyroid cells. Left control: $[Ca^{2+}]_i$ was initially 0.5 mM and was increased in 0.5 mM increments at each of the open
10 arrowheads before the addition of neomycin B (30 μ M). Right: Neomycin B (30 μ M) was added before $[Ca^{2+}]_i$. Bar = 1 minute.

Figs. 13a and 13b are graphical representations showing that neomycin B or protamine inhibit PTH secretion at concentrations which evoked increases in $[Ca^{2+}]_i$ in bovine
15 parathyroid cells. Cells were incubated with the indicated concentrations of organic polycation for 30 minutes in the presence of 0.5 mM extracellular Ca^{2+} . Bovine cells were used in the experiments with protamine and human (adenoma) parathyroid cells were used in the experiments with neomycin
20 B. Each point is the mean \pm SEM of 3 experiments. Circles refer to PTH levels in the presence of 0.5 mM extracellular Ca^{2+} in the presence (closed circles) and absence (open circles) of neomycin B (Fig. 13a) or protamine (Fig. 13b). Diamonds refer to $[Ca^{2+}]_i$ levels in the presence of 0.5 mM
25 extracellular Ca^{2+} in the presence (closed diamonds) and absence (open diamond) of neomycin B (Fig. 13a) or protamine (Fig. 13b). The open square refers to PTH secretion in the presence of 2 mM extracellular Ca^{2+} .

Fig. 14 is a graphical representation showing the
30 preferential inhibitory effects of PMA on cytosolic Ca^{2+} transients elicited by spermine in bovine parathyroid cells. Initial $[Ca^{2+}]_i$ was 0.5 mM; PMA (100 nM), spermine (200 μ M) or ATP (50 μ M) were added as indicated. Bar = 1 minute.

Figs. 15a and 15b are graphical representations showing that PMA shifts to the right the concentration-response curves for extracellular Ca^{2+} - and neomycin B-induced increases in $[\text{Ca}^{2+}]_i$ in bovine parathyroid cells. Cells were
 5 either untreated (open circles) or pretreated with 100 nM PMA for 1 minute (closed circles) before increasing $[\text{Ca}^{2+}]$ or before adding neomycin B as indicated. Each point is the mean \pm SEM of 3 to 5 experiments.

Figs. 16a and 16b are graphical representations showing
 10 that PMA shifts to the right the concentration-response curves for extracellular Ca^{2+} - and spermine-induced inhibition of PTH secretion in bovine parathyroid cells. Cells were incubated with the indicated $[\text{Ca}^{2+}]$ and spermine for 30 minutes in the presence (closed circles) or absence
 15 (open circles) of 100 nM PMA. Each point is the mean \pm SEM of 3 experiments.

Fig. 17 is a graphical representation showing that protamine increases the formation of inositol phosphates in bovine parathyroid cells. Parathyroid cells were incubated
 20 overnight in culture media containing 4 $\mu\text{Ci/ml}$ ^3H -myo-inositol, washed, and incubated with the indicated concentration of protamine at 37°C . After 30 seconds, the reaction was terminated by the addition of $\text{CHCl}_3:\text{MeOH}:\text{HCl}$ and IP_1 (circles) and IP_2 (triangles) separated by anion exchange
 25 chromatography. Each point is the mean of 2 experiments, each performed in triplicate.

Figs. 18a and 18b are graphical representations showing that PMA depresses the formation of IP_1 evoked by extracellular Ca^{2+} or spermine in bovine parathyroid cells.
 30 ^3H -Myo-inositol-labeled cells were exposed to the indicated $[\text{Ca}^{2+}]_i$ or spermine for 30 seconds before terminating the reaction and determining IP_1 by anion exchange chromatography. Hatched columns: Cells were pretreated with PMA (100 nM) for 5 minutes before increasing $[\text{Ca}^{2+}]_i$ or adding

spermine. Each value is the mean of 2 experiments, each performed in triplicate.

Fig. 19 is a graphical representation showing transient and sustained increases in $[Ca^{2+}]_i$ elicited by neomycin B in human (adenoma) parathyroid cells. Extracellular Ca^{2+} was 0.5 mM. (a) The sustained increase in $[Ca^{2+}]_i$ elicited by neomycin B (10 μ M) was depressed by La^{3+} (1 μ M). (b) The transient increase in $[Ca^{2+}]_i$ evoked by neomycin B (10 μ M) was unaffected by La^{3+} (1 μ M). (c) Transient increases in $[Ca^{2+}]_i$ persisted in the absence of extracellular Ca^{2+} (1 mM of EGTA and 10 μ M of neomycin B).

Figs. 20a and 20b are graphical representations showing that neomycin B evokes oscillating increases the Cl^- current in *Xenopus* oocytes expressing the calcium receptor. Upper trace from an oocyte three days after injection with human (hyperplastic) parathyroid cell poly(A)⁺-mRNA. Lower trace from an oocyte injected with water. Neomycin B failed to elicit a response in five water-injected oocytes and carbachol elicited a response in one, which is shown. In both traces, the holding potential was -76 mV.

Fig. 21 is a graphical representation showing that neomycin B fails to affect basal or evoked increases in C-cells. Control, left trace: fura-2-loaded rMTC 6-23 cells were initially bathed in buffer containing 1 mM Ca^{2+} before increasing $[Ca^{2+}]_i$ to 3 mM. Right trace: pretreatment with 5 mM neomycin B.

Fig. 22 is a graphical representation showing that extracellular Ca^{2+} evokes increases in $[Ca^{2+}]_i$ in rat osteoclasts. Microfluorimetric recording in a single rat osteoclast loaded with indo-1 and superfused for the indicated times (bars) with buffer containing the indicated $[Ca^{2+}]$. Normal buffer, superfused between the bars, contained 1 mM Ca^{2+} .

Fig. 23 is a graphical representation showing that spermine or neomycin B fail to evoke increases in $[Ca^{2+}]_i$ in rat osteoclasts. An indo-1-loaded osteoclast was superfused with the indicated concentration of spermine or neomycin B (open bars) alone or together with 20 mM Ca^{2+} (solid bars).

Fig. 24 is a graphical representation showing the differential effects of argiotoxin 659 and argiotoxin 636 on $[Ca^{2+}]_i$ in bovine parathyroid cells (structures shown in Fig. 1e). The initial $[Ca^{2+}]_i$ was 0.5 mM and was increased to 1.5 mM where indicated (right trace). Where indicated, argiotoxin 659 (300 μ M) or argiotoxin 636 (400 μ M) was added.

Figs. 25a-25c are graphical representations showing that extracellular Mg^{2+} or Gd^{3+} evoke oscillatory increases in Cl^- current in *Xenopus* oocytes injected with bovine parathyroid cell poly(A)⁺-mRNA. In trace (a), the concentration of extracellular Ca^{2+} was < 1 μ M and in traces (b) and (c) it was 0.7 mM. Trace (c) shows that extracellular Mg^{2+} fails to elicit a response in an oocyte injected only with the mRNA for the substance K receptor, although superfusion with substance K evokes a response. Holding potential was -70 to -80 mV.

Fig. 26 is a graphical representation showing that extracellular Ca^{2+} elicits oscillatory increases in Cl^- current in *Xenopus* oocytes injected with human (hyperplastic) parathyroid tissue poly(A)⁺-mRNA. The oocyte was tested for responsivity to extracellular Ca^{2+} three days after injection of 50 ng poly(A)⁺-mRNA. Holding potential was -80 mV.

Fig. 27 is a graphical representation showing the mobilization of intracellular Ca^{2+} in bovine parathyroid cells elicited by budmunchiamine. Budmunchiamine (300 μ M, structure shown in Fig. 1a) was added where indicated.

Figs. 28a and 28b are graphical representations showing that the ability of molecules to mobilize intracellular Ca^{2+} in cells expressing a calcium receptor is stereospecific.

Different cells were tested for response to pure stereoisomers and racemic mixtures. HEK 293 cells stably transfected with a cDNA clone corresponding to pHuPCaR4.0 (top panel, Fig. 28b), the rat C-cell line 44-2 isolated from a medullary thyroid carcinoma (middle panel, Fig 28b) and bovine parathyroid cells (Fig. 28a and bottom panel Fig. 28b) were loaded with fura-2 and suspended in buffer containing 1.0 mM (top and middle panels Fig. 28b) or 0.5 mM extracellular Ca^{2+} (Fig. 28a and bottom panel Fig. 28b). Intracellular Ca^{2+} was monitored using a fluorimeter. Each point on the graph represents the peak response (highest concentration of intracellular calcium achieved) to the addition of the indicated concentration of the indicated compound. In Fig. 28a, NPS 457 is a racemic mixture containing compound 1B (see figure 36a) and the corresponding *S* isomer; NPS 447 is *R*-fendiline; and NPS 448 is *S*-fendiline.

Fig. 29 is a graphical representation showing effects of La^{3+} on $[\text{Ca}^{2+}]_i$ in osteoclasts. A representative trace from a single rat osteoclast loaded with indo-1 is shown. At low concentrations, La^{3+} partially blocks increases in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} .

Figs. 30a and 30b are graphical representations showing the mobilization of intracellular Ca^{2+} elicited by extracellular Mn^{2+} in rat osteoclasts. Extracellular Mn^{2+} evokes concentration-dependent increases in $[\text{Ca}^{2+}]_i$ (Fig. 30a) that persist in the absence of extracellular Ca^{2+} (Fig. 30b).

Figs. 31a and 31b are graphical representations showing mobilization of $[\text{Ca}^{2+}]_i$ in rat osteoclasts elicited by prenylamine (shown in the figures as NPS 449). Isolated rat osteoclasts loaded with indo-1 were superfused with the indicated concentrations of prenylamine in the presence (Fig. 31a) or absence (Fig. 31b) of 1 mM extracellular CaCl_2 .

Fig. 32 is a graphical representation showing the mobilization of intracellular Ca^{2+} in C-cells evoked by NPS

019 (see Fig. 1a). rMTC 6-23 cells were loaded with fura-2 and bathed in buffer containing 0.5 mM $[Ca^{2+}]$. Where indicated, NPS 019 was added to a final concentration of 10 μ M. Representative traces show that the transient increase in $[Ca^{2+}]$, elicited by NPS 019 is refractory to inhibition by La^{3+} (middle trace) and persists in the absence of extracellular Ca^{2+} (right trace, 1 mM EGTA).

Fig. 33 is a graphical representation showing that fendiline (shown in the figure as NPS 456) evokes oscillatory increases in Cl^- current in *Xenopus* oocytes which have been injected with 50 ng bovine parathyroid cell poly(A)⁺-mRNA.

Fig. 34 is a graphical representation showing that extracellular Ca^{2+} evokes oscillatory increases in Cl^- current in *Xenopus* oocytes which have been injected with human osteoclast mRNA. The oocyte was tested for responsivity to extracellular Ca^{2+} three days after injection of 50 ng of total poly(A)⁺-mRNA.

Fig. 35 is a graphical representation showing that the parathyroid cell calcium receptor is encoded by mRNA in a size range of 2.5-3.5 kb. Bovine parathyroid cell poly(A)⁺-mRNA was size fractionated on glycerol gradients and pooled into ten fractions. Each fraction was injected (50 ng/fraction) separately into *Xenopus* oocytes. After three days, the oocytes were examined for their ability to respond to neomycin B (10 mM) with oscillatory increases in the Cl^- current.

Fig. 36 shows the chemical structures of molecules based on the lead structure diphenylpropyl- α -phenethylamine (fendeline), illustrating a family of molecules which were synthesized and screened to find the useful molecules of the invention.

Figs. 37a and 37b are graphical representations showing that NPS 021 is a calcilytic compound that blocks the effects of extracellular Ca^{2+} on $[Ca^{2+}]$, in bovine parathyroid cells.

Cells were initially bathed in buffer containing 0.5 mM CaCl_2 and, where indicated, the $[\text{Ca}^{2+}]$ was increased to a final of 2 mM (left trace). The addition of NPS 021 (200 μM) caused no change in $[\text{Ca}^{2+}]_i$, but inhibited the increase in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} (right trace).

Fig. 38 is a graph showing the *in vivo* serum Ca^{2+} response to NPS R,S-467 in a test animal (a rat). The dosage is provided as mg of drug per kg weight of the test animal.

Fig. 39 is a graph showing the *in vivo* PTH response to NPS R,S-467 in a test animal (a rat). The dosage is provided as mg of drug per kg weight of the test animal.

Fig. 40 is a graph showing *in vivo* serum Ca^{2+} response over the course of 24 hours to 25 mg/kg NPS R,S-467 in a test animal (a rat). The dosage is provided as mg of drug per kg weight of the test animal.

Fig. 41 is a graph showing the *in vitro* response of $[\text{Ca}^{2+}]_i$ in cultured bovine parathyroid cells to different enantiomers of NPS 467. EE refers to the R enantiomer. LE and to the S enantiomer.

Fig. 42 is a graph showing the *in vivo* response of ionized serum Ca^{2+} in rats to different enantiomers of NPS 467. DE and E refer to the R enantiomer. LE and L refer to the S enantiomer. Native refers to the racemic mixture.

Fig. 43a depicts a reaction scheme for the preparation of fendiline or fendiline analogues or derivatives depicted in Figure 36. Fig. 43b depicts a reaction scheme for the synthesis of NPS 467.

Fig. 44 depicts a dose-response curve showing that NPS R-467 (NPS-467E) lowers serum ionized calcium in rats when administered orally.

Fig. 45 is a restriction map of BoPCaR 1.

Fig. 46 is a restriction map of the plasmid containing BoPCaR 1, deposited with the ATCC under accession number 75416.

Figs. 47a-d show the nucleotide sequence corresponding to the ~5 Kb fragment of BoPCaR 1 and the encoded-for amino acid sequence (SEQ. ID. NO. 1).

5 Figs. 48a-48d show the nucleotide sequence corresponding to the ~5 Kb insert from pHuPCaR 5.2 and the encoded-for amino acid sequence (SEQ. ID. NO. 2).

Figs. 49a-49c show the nucleotide sequence corresponding to the ~4 Kb insert from pHuCaR 4.0 and the encoded-for amino acid sequence (SEQ. ID. NO. 3).

10 Figs. 50a-50c show the nucleotide sequence corresponding to the ~4 Kb insert of pRakCaR 3A and the encoded-for amino acid sequence (SEQ. ID. NO. 4).

Fig. 51 depicts the ability of NPS R-467 and NPS R-568 to potentiate the response of a calcium receptor to
15 submaximal concentrations of extracellular Ca^{2+} , and shift the extracellular Ca^{2+} concentration-response curve to the left.

Fig. 52 depicts a reaction scheme for compound 17X.

20 DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention features: (1) molecules which can modulate one or more inorganic ion receptor activities, preferably the molecule can mimic or block an effect of an extracellular ion on a cell having an inorganic ion receptor,
25 more preferably the extracellular ion is Ca^{2+} and the effect is on a cell having a calcium receptor; (2) inorganic ion receptor proteins and fragments thereof, preferably calcium receptor proteins and fragments thereof; (3) nucleic acids encoding inorganic ion receptor proteins and fragments
30 thereof, preferably calcium receptor proteins and fragments thereof; (4) antibodies and fragments thereof, targeted to inorganic ion receptor proteins, preferably calcium receptor protein; and (5) uses of such molecules, proteins, nucleic acids and antibodies.

Applicant is the first to demonstrate a Ca^{2+} receptor protein in parathyroid cells, and to pharmacologically differentiate such Ca^{2+} receptors in other cells, such as C-cells and osteoclasts. Applicant is also the first to describe methods by which molecules active at these Ca^{2+} receptors can be identified and used as lead molecules in the discovery, development, design, modification and/or construction of useful calcimimetics or calcilytics which are active at Ca^{2+} receptors.

Publications concerned with the calcium activity, calcium receptor and/or calcium receptor modulating compounds include the following: Brown et al., Nature 366: 574, 1993; Nemeth et al., PCT/US93/01642, International Publication Number WO 94/18959; Nemeth et al., PCT/US92/07175, International Publication Number WO 93/04373; Shoback and Chen, J. Bone Mineral Res. 9: 293 (1994); and Racke et al., FEBS Lett. 333: 132, (1993). These publications are not admitted to be prior art to the claimed invention.

I. CALCIUM RECEPTOR-MODULATING AGENTS

Calcium receptor-modulating agents can mimic or block an effect of extracellular Ca^{2+} on cell having a calcium receptor. Generic and specific structures of calcium receptor-modulating agents are provided in the Summary *supra*, and in Figures 1 and 36. Preferred calcium receptor-modulating agents are calcimimetics and calcilytics. The ability of molecules to mimic or block an activity of Ca^{2+} at calcium receptors can be determined using procedures described below. The same type of procedures can be used to measure the ability of a molecule to mimic or block an activity of other inorganic ions at their respective inorganic ion receptors by assaying for specific inorganic ion receptor activities. Examples of these procedures, and other examples provided herein, are not limiting, in the

invention, but merely illustrate methods which are readily used or adapted by those of ordinary skill in the art.

A. Calcium Receptor

5 Calcium receptors are present on different cell types and can have different activities in different cell types. The pharmacological effects of the following cells, in response to calcium, is consistent with the presence of a calcium receptor: parathyroid cell, bone osteoclast,
 10 juxtaglomerular kidney cell, proximal tubule kidney cell, distal tubule kidney cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct, keratinocyte in the epidermis, parafollicular cell in the thyroid (C-cell),
 15 intestinal cell, trophoblast in the placenta, platelet, vascular smooth muscle cell, cardiac atrial cell, gastrin-secreting cell, glucagon-secreting cell, kidney mesangial cell, mammary cell, beta cell, fat/adipose cell, immune cell, GI tract cell, skin cell, adrenal cell, pituitary cell,
 20 hypothalamic cell and cell of the subfornical organ. In addition, the presence of calcium receptors on parathyroid cell, central nervous system cell, peripheral nervous system cell, cell of the thick ascending limb of Henle's loop and/or collecting duct in the kidney, parafollicular cell in the
 25 thyroid (C-cell), intestinal cell, GI tract cell, pituitary cell, hypothalamic cell and cell of the subfornical organ, has been confirmed by physical data.

The calcium receptor on these cell types may be different. It is also possible that a cell can have more
 30 than one type of calcium receptor. Comparison of calcium receptor activities and amino acid sequences from different cells indicate that distinct calcium receptor types exist. For example, calcium receptors can respond to a variety of di- and trivalent cations. The parathyroid calcium receptor

responds to calcium and Gd^{3+} , while osteoclasts respond to divalent cations such as calcium, but do not respond to Gd^{3+} . Thus, the parathyroid calcium receptor is pharmacologically distinct from the calcium receptor on the osteoclast.

5 On the other hand, the nucleic acid sequences encoding calcium receptors present in parathyroid cells and C-cells indicate that these receptors have a very similar amino acid structure. Nevertheless, calcimimetic compounds exhibit differential pharmacology and regulate different activities
10 at parathyroid cells and C-cells. Thus, pharmacological properties of calcium receptors may vary significantly depending upon the cell type or organ in which they are expressed even though the calcium receptors may have similar or even identical structures.

15 Calcium receptors, in general, have a low affinity for extracellular Ca^{2+} (apparent K_d generally greater than about 0.5 mM). Calcium receptors may include a free or bound effector mechanism as defined by Cooper, Bloom and Roth, "The Biochemical Basis of Neuropharmacology", Ch. 4, and are thus
20 distinct from intracellular calcium receptors, e.g., calmodulin and the troponins.

 Calcium receptors respond to changes in extracellular calcium levels. The exact changes depend on the particular receptor and cell line containing the receptor. For example,
25 the *in vitro* effect of calcium on the calcium receptor in a parathyroid cell includes the following:

 1. An increase in internal calcium. The increase is due to the influx of external calcium and/or to mobilization of internal calcium. Characteristics of the
30 increase in internal calcium include the following:

 (a) A rapid (time to peak < 5 seconds) and transient increase in $[Ca^{2+}]_i$ that is refractory to inhibition by 1 μM La^{3+} or 1 μM Gd^{3+} and is abolished by pretreatment with ionomycin (in the absence of extracellular Ca^{2+});

(b) The increase is not inhibited by dihydropyridines;

(c) The transient increase is abolished by pretreatment for 10 minutes with 10 mM sodium fluoride;

5 (d) The transient increase is diminished by pretreatment with an activator of protein kinase C (PKC), such as phorbol myristate acetate (PMA), mezerein or (-)-indolactam V. The overall effect of the protein kinase C activator is to shift the concentration-response curve of
10 calcium to the right without affecting the maximal response; and

(e) Pretreatment with pertussis toxin (100 ng/ml for > 4 hours) does not affect the increase.

2. A rapid (< 30 seconds) increase in the
15 formation of inositol-1,4,5-triphosphate or diacylglycerol. Pretreatment with pertussis toxin (100 ng/ml for > 4 hours) does not affect this increase;

3. The inhibition of dopamine- and isoproterenol-stimulated cyclic AMP formation. This effect is blocked by
20 pretreatment with pertussis toxin (100 ng/ml for > 4 hours); and

4. The inhibition of PTH secretion. Pretreatment with pertussis toxin (100 ng/ml for > 4 hours) does not affect the inhibition in PTH secretion.

25 Using techniques known in the art, the effect of calcium on other calcium receptors in different cells can be readily determined. Such effects may be similar in regard to the increase in internal calcium observed in parathyroid cells. However, the effect is expected to differ in other aspects,
30 such as causing or inhibiting the release of a hormone other than parathyroid hormone.

B. Calcimimetics

The ability of molecules to mimic or block the activity of Ca^{2+} at calcium receptors can be determined using the assays described in the present application. For example, calcimimetics possess one or more and preferably all of the following activities when tested on parathyroid cells *in vitro*:

1. The molecule causes a rapid (time to peak < 5 seconds) and transient increase in $[\text{Ca}^{2+}]_i$ that is refractory to inhibition by $1 \mu\text{M}$ La^{3+} or $1 \mu\text{M}$ Gd^{3+} . The increase in $[\text{Ca}^{2+}]_i$ persists in the absence of extracellular Ca^{2+} , but is abolished by pretreatment with ionomycin (in the absence of extracellular Ca^{2+});
2. The molecule potentiates increases in $[\text{Ca}^{2+}]_i$ elicited by submaximal concentrations of extracellular Ca^{2+} ;
3. The increase in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} is not inhibited by dihydropyridines;
4. The transient increase in $[\text{Ca}^{2+}]_i$ caused by the molecule is abolished by pretreatment for 10 minutes with 10 mM sodium fluoride;
5. The transient increase in $[\text{Ca}^{2+}]_i$ caused by the molecule is diminished by pretreatment with an activator of protein kinase C (PKC), such as phorbol myristate acetate (PMA), mezerein or (-)-indolactam V. The overall effect of the protein kinase C activator is to shift the concentration-response curve of the molecule to the right without affecting the maximal response;
6. The molecule causes a rapid (< 30 seconds) increase in the formation of inositol-1,4,5-triphosphate and/or diacylglycerol;
7. The molecule inhibits dopamine- or isoproterenol-stimulated cyclic AMP formation;
8. The molecule inhibits PTH secretion;
9. Pretreatment with pertussis toxin (100 ng/ml for > 4 hours) blocks the inhibitory effect of the molecule

on cyclic AMP formation, but does not effect increases in $[Ca^{2+}]_i$, inositol-1,4,5-triphosphate, or diacylglycerol, nor decreases in PTH secretion;

10. The molecule elicits increases in Cl^- current
5 in *Xenopus* oocytes injected with poly(A)⁺-enriched mRNA from bovine or human parathyroid cells, but is without effect in *Xenopus* oocytes injected with water, or liver mRNA; and

11. Similarly, using a cloned calcium receptor
10 from a parathyroid cell, the molecule will elicit a response in *Xenopus* oocytes injected with the specific cDNA or mRNA encoding the receptor.

Parallel definitions of molecules mimicking Ca^{2+}
activity on other calcium-responsive cells, preferably at a
calcium receptor, are evident from the examples provided
15 herein. Preferably, the agent has one or more, more preferably all of the following activities: evokes a transient increase in internal calcium, having a duration of less than 30 seconds (preferably by mobilizing internal calcium); evokes a rapid increase in $[Ca^{2+}]_i$, occurring within
20 thirty seconds; evokes a sustained increase (greater than thirty seconds) in $[Ca^{2+}]_i$ (preferably by causing an influx of external calcium); evokes an increase in inositol-1,4,5-triphosphate or diacylglycerol levels, preferably within less than 60 seconds; and inhibits dopamine- or isoproterenol-
25 stimulated cyclic AMP formation.

The transient increase in $[Ca^{2+}]_i$ is preferably abolished by pretreatment of the cell for ten minutes with 10 mM sodium fluoride, or the transient increase is diminished by brief pretreatment (not more than ten minutes) of the cell with an
30 activator of protein kinase C, preferably, phorbol myristate acetate (PMA), mezerein or (-) indolactam V.

C. Calcilytics

The ability of a molecule to block or decrease the activity of extracellular calcium at a cell surface calcium receptor can be determined using standard techniques based on the present disclosure. For example, molecules which block or decrease the effect of extracellular calcium, when used in reference to a parathyroid cell, possess one or more, and preferably all of the following characteristics when tested on parathyroid cells in vitro:

1. The molecule blocks, either partially or completely, the ability of increased concentrations of extracellular Ca^{2+} to:

- (a) increase $[\text{Ca}^{2+}]_i$,
- (b) mobilize intracellular Ca^{2+} ,
- (c) increase the formation of inositol-1,4,5-triphosphate,
- (d) decrease dopamine- or isoproterenol-stimulated cyclic AMP formation, and
- (e) inhibit PTH secretion;

2. The molecule blocks increases in Cl^- current in *Xenopus* oocytes injected with poly(A)⁺-mRNA from bovine or human parathyroid cells elicited by extracellular Ca^{2+} or calcimimetic compounds, but not in *Xenopus* oocytes injected with water or liver mRNA;

3. Similarly, using a cloned calcium receptor from a parathyroid cell, the molecule will block a response in *Xenopus* oocytes injected with the specific cDNA, mRNA or cRNA encoding the calcium receptor, elicited by extracellular Ca^{2+} or a calcimimetic compound.

Parallel definitions of molecules blocking Ca^{2+} activity on other calcium responsive cells, preferably at a calcium receptor, are evident from the examples provided herein.

D. Designing Calcium Receptor-Modulating Agents

Generally, calcium receptor-modulating agents are identified by screening molecules which are modelled after a molecule shown to have a particular activity (i.e., a lead molecule). Derivative molecules are readily designed by standard procedures and tested using the procedures described herein.

Rational design of calcium receptor-modulating agents involves studying a molecule known to be calcimimetic or calcilytic and then modifying the structure of the known molecule. For example, polyamines are potentially calcimimetic since spermine mimics the action of Ca^{2+} in several *in vitro* systems. Results show that spermine does indeed cause changes in $[\text{Ca}^{2+}]_i$ and PTH secretion reminiscent of those elicited by extracellular di- and trivalent cations (see below). Conversely, Ga^{3+} antagonizes the effects of Gd^{3+} on the bovine parathyroid calcium receptor(s). The experiments outlined below are therefore aimed at demonstrating that this phenomenology, obtained with spermine, involves the same mechanisms used by extracellular Ca^{2+} . To do this, the effects of spermine on a variety of physiological and biochemical parameters which characterize activation of the calcium receptor were assessed. Those molecules having similar types of effects, and preferably at a greater magnitude, are useful in this invention and can be discovered by selecting or making molecules having a structure similar to spermine. Once another useful molecule is discovered this selection process can be readily repeated. The same type of analysis can be preformed using different lead molecules shown to have desired activity.

For clarity, a specific series of screening protocols to identify molecules active at a parathyroid cell calcium receptor is described below. Equivalent assays can be used for molecules active at other calcium receptors or other inorganic ion receptors, or which otherwise mimic or

antagonize cellular functions regulated by extracellular $[Ca^{2+}]$ at a calcium receptor. These assays exemplify the procedures which are useful to find molecules, including calcimimetic molecules, of this invention. Equivalent
5 procedures can be used to find ionolytic molecules, including calcilytic molecules, by screening for those molecules most antagonistic to the actions of the ion, including extracellular Ca^{2+} . In vitro assays can be used to characterize the selectivity, saturability, and reversibility
10 of these calcimimetics and calcilytics by standard techniques.

1. Screening Procedures

Various screening procedures can be carried out to
15 assess the ability of a compound to act as a calcilytic or calcimimetic by measuring its ability to have one or more activities of a calcilytic or calcimimetic. In the case of parathyroid cells, such activities include the effects on intracellular calcium, inositol phosphates, cyclic AMP and
20 PTH.

Measuring $[Ca^{2+}]$, with fura-2 provides a very rapid means of screening new organic molecules for activity. In a single afternoon, 10-15 compounds (or molecule types) can be examined and their ability to mobilize or inhibit
25 mobilization of intracellular Ca^{2+} can be assessed by a single experimenter. The sensitivity of observed increases in $[Ca^{2+}]$, to depression by PMA can also be assessed.

For example, bovine parathyroid cells loaded with fura-2 are initially suspended in buffer containing 0.5 mM $CaCl_2$.
30 A test substance is added to the cuvette in a small volume (5-15 μ l) and changes in the fluorescence signal are measured. Cumulative increases in the concentration of the test substance are made in the cuvette until some predetermined concentration is achieved or no further changes

in fluorescence are noted. If no changes in fluorescence are noted, the molecule is considered inactive and no further testing is performed.

In the initial studies, e.g., with polyamine-type molecules, molecules were tested at concentrations as high as 5 or 10 mM. As more potent molecules became known, the ceiling concentration was lowered. For example, newer molecules are tested at concentrations no greater than 500 μ M. If no changes in fluorescence are noted at this concentration, the molecule can be considered inactive.

Molecules causing increases in $[Ca^{2+}]_i$ are subjected to additional testing. Two characteristics of a molecule which can be considered in screening a calcimimetic molecule are the mobilization of intracellular Ca^{2+} and sensitivity to PKC activators. Molecules causing the mobilization of intracellular Ca^{2+} in a PMA-sensitive manner have invariably been found to be calcimimetic molecules and to inhibit PTH secretion. Sensitivity to PKC activators is measured in cells where PKC has not undergone treatment resulting in persistent activation. Chronic pretreatment with low concentrations of PMA (about 30 - 100 nM treatment for about 24 hours) results in persistent activation of PKC and allows for the inhibition of PTH secretion by extracellular Ca^{2+} without any accompanying increase in $[Ca]_i$.

A single preparation of cells can provide data on $[Ca^{2+}]_i$, cyclic AMP levels, IP_3 and PTH secretion. A typical procedure is to load cells with fura-2 and then divide the cell suspension in two; most of the cells are used for measurement of $[Ca^{2+}]_i$ and the remainder are incubated with molecules to assess their effects on cyclic AMP and PTH secretion. Because of the sensitivity of the radioimmunoassays for cyclic AMP and PTH, both variables can be determined in a single incubation tube containing 0.3 ml cell suspension (about 500,000 cells).

Measurements of inositol phosphates are a time-consuming aspect of the screening. However, ion-exchange columns eluted with chloride (rather than formate) provide a very rapid means of screening for IP_3 formation, since rotary evaporation (which takes around 30 hours) is not required. This method allows processing of nearly 100 samples in a single afternoon by a single experimenter. Those molecules that prove interesting, as assessed by measurements of $[Ca^{2+}]_i$, cyclic AMP, IP_3 , and PTH, can be subjected to a more rigorous analysis by examining formation of various inositol phosphates and assessing their isomeric form by HPLC.

Additional testing can, if needed, be performed to confirm the ability of a molecule to act as a calcimimetic prior to its use to inhibit PTH in human cells or test animals. Typically, all the various tests for calcimimetic or calcilytic activity are not performed. Rather, if a molecule causes the mobilization of intracellular Ca^{2+} in a PMA-sensitive manner, it is advanced to screening on human parathyroid cells. For example, measurements of $[Ca^{2+}]_i$ are performed to determine the EC_{50} , and to measure the ability of the molecule to inhibit PTH secretion in human parathyroid cells which have been obtained from patients undergoing surgery for primary or secondary hyperparathyroidism. The lower the EC_{50} or IC_{50} , the more potent the molecule as a calcimimetic or calcilytic.

Calcimimetic and calcilytic molecules affecting PTH secretion are then preferably assessed for selectivity, for example, by also examining the effects of such compounds on $[Ca^{2+}]_i$ or calcitonin secretion in calcitonin-secreting C-cells such as the rat MTC 6-23 cells.

The following is illustrative of methods useful in these screening procedures. Examples of typical results for various test calcimimetic or calcilytic molecules are provided in Figs. 2-34.

(a) Parathyroid Cell Preparation

This section describes procedures used to obtain and treat parathyroid cells from calves and humans. Parathyroid glands were obtained from freshly slaughtered calves (12-15 weeks old) at a local abattoir and transported to the laboratory in ice-cold parathyroid cell buffer (PCB) which contains (mM): NaCl, 126; KCl, 4; MgCl₂, 1; Na-HEPES, 20; pH 7.4; glucose, 5.6, and variable amounts of CaCl₂, e.g., 1.25 mM. Human parathyroid glands, were obtained from patients undergoing surgical removal of parathyroid tissue for primary or uremic hyperparathyroidism (uremic HPT), and were treated similarly to bovine tissue.

Glands were trimmed of excess fat and connective tissue and then minced with fine scissors into cubes approximately 2-3 mm on a side. Dissociated parathyroid cells were prepared by collagenase digestion and then purified by centrifugation in Percoll buffer. The resultant parathyroid cell preparation was essentially devoid of red blood cells, adipocytes, and capillary tissue as assessed by phase contrast microscopy and Sudan black B staining. Dissociated and purified parathyroid cells were present as small clusters containing 5 to 20 cells. Cellular viability, as indexed by exclusion of trypan blue or ethidium bromide, was routinely 95%.

Although cells can be used for experimental purposes at this point, physiological responses (e.g., suppressibility of PTH secretion and resting levels of [Ca²⁺]_i) should be determined after culturing the cells overnight. Primary culture also has the advantage that cells can be labeled with isotopes to near isotopic equilibrium, as is necessary for studies involving measurements of inositol phosphate metabolism.

After purification on Percoll gradients, cells were washed several times in a 1:1 mixture of Ham's F12-Dulbecco's

modified Eagle's medium (GIBCO) supplemented with 50 $\mu\text{g/ml}$ streptomycin, 100 U/ml penicillin, 5 $\mu\text{g/ml}$ gentamicin and ITS⁺. ITS⁺ is a premixed solution containing insulin, transferrin, selenium, and bovine serum albumin (BSA)-linolenic acid (Collaborative Research, Bedford, MA). The cells were then transferred to plastic flasks (75 or 150 cm²; Falcon) and incubated overnight at 37°C in a humid atmosphere of 5% CO₂. No serum is added to these overnight cultures, since its presence allows the cells to attach to the plastic, undergo proliferation, and dedifferentiate. Cells cultured under the above conditions were readily removed from the flasks by decanting, and show the same viability as freshly prepared cells.

15 **(b) Measurement of Cytosolic Ca²⁺ in Parathyroid Cells**

This section describes procedures used to measure cytosolic Ca²⁺ in parathyroid cells. Purified parathyroid cells were resuspended in 1.25 mM CaCl₂-2% BSA-PCB containing 1 μM fura-2-acetoxymethylester and incubated at 37°C for 20 minutes. The cells were then pelleted, resuspended in the same buffer, but lacking the ester, and incubated a further 15 minutes at 37°C. The cells were subsequently washed twice with PCB containing 0.5 mM CaCl₂ and 0.5% BSA and maintained at room temperature (about 20°C). Immediately before use, the cells were diluted five-fold with prewarmed 0.5 mM CaCl₂-PCB to obtain a final BSA concentration of 0.1%. The concentration of cells in the cuvette used for fluorescence recording was 1-2 x 10⁶/ml.

The fluorescence of indicator-loaded cells was measured at 37°C in a spectrofluorimeter (Biomedical Instrumentation Group, University of Pennsylvania, Philadelphia, PA) equipped with a thermostated cuvette holder and magnetic stirrer using excitation and emission wavelengths of 340 and 510 nm, respectively. This fluorescence indicates the level of

cytosolic Ca^{2+} . Fluorescence signals were calibrated using digitonin (50 $\mu\text{g}/\text{ml}$, final) to obtain maximum fluorescence (F_{max}), and EGTA (10 mM, pH 8.3, final) to obtain minimal fluorescence (F_{min}), and a dissociation constant of 224 nM.

- 5 Leakage of dye is dependent on temperature and most occurs within the first 2 minutes after warming the cells in the cuvette. Dye leakage increases only very slowly thereafter. To correct the calibration for dye leakage, cells were placed in the cuvette and stirred at 37°C for 2-3 minutes. The cell
10 suspension was then removed, the cells pelleted, and the supernatant returned to a clean cuvette. The supernatant was then treated with digitonin and EGTA to estimate dye leakage, which is typically 10-15% of the total Ca^{2+} -dependent fluorescent signal. This estimate was subtracted from the
15 apparent F_{min} .

(c) Measurement of Cytosolic Ca^{2+} in C-cells

- This section describes procedures used to measure cytosolic Ca^{2+} in cells. Neoplastic C-cells derived from a
20 rat medullary thyroid carcinoma (rMTC 6-23) were obtained from American Type Culture Collection (ATCC No. 1607) and cultured as monolayers in Dulbecco's Modified Eagle's medium (DMEM) plus 15% horse serum in the absence of antibiotics. For measurements of $[\text{Ca}^{2+}]_i$, the cells were harvested with
25 0.02% EDTA/0.05% trypsin, washed twice with PCB containing 1.25 mM CaCl_2 and 0.5% BSA, and loaded with fura-2 as described in section I.D.2(b), *supra*. Measurements of $[\text{Ca}^{2+}]_i$ were performed as described above with appropriate corrections for dye leakage.

(d) Measurement of $[Ca^{2+}]_i$ in Rat Osteoclasts

This section describes techniques used to measure $[Ca^{2+}]_i$ in rat osteoclasts. Osteoclasts were obtained from 1-2 day old Sprague-Dawley rats using aseptic conditions. The rat
5 pups were sacrificed by decapitation, the hind legs removed, and the femora rapidly freed of soft tissue and placed in prewarmed F-12/DMEM media (DMEM containing 10% fetal calf serum and antibiotics (penicillin-streptomycin-gentamicin; 100 U/ml-100 μ g/ml-100 μ g/ml)). The bones from two pups were
10 cut lengthwise and placed in 1 ml culture medium. Bone cells were obtained by gentle trituration of the bone fragments with a plastic pipet and diluted with culture medium. The bone fragments were allowed to settle and equal portions (about 1 ml) of the medium transferred to a 6-well culture
15 plate containing 25-mm glass coverslips. The cells were allowed to settle for 1 hour at 37°C in a humidified 5% CO₂-air atmosphere. The coverslips were then washed 3 times with fresh media to remove nonadherent cells. Measurements of $[Ca^{2+}]_i$ in osteoclasts were performed within 6-8 hours of
20 removing nonadherent cells.

Cells attached to the coverslip were loaded with indo-1 by incubation with 5 μ M indo-1 acetoxymethylester/0.01% Pluronic F28 for 30 minutes at 37°C in F-12/DMEM lacking serum and containing instead 0.5% BSA. The coverslips were
25 subsequently washed and incubated an additional 15 minutes at 37°C in F-12/DMEM lacking the acetoxyster before being transferred to a superfusion chamber mounted on the stage of a Nikon Diaphot inverted microscope equipped for microfluorimetry. Osteoclasts were easily identified by
30 their large size and presence of multiple nuclei. The cells were superfused with buffer (typically PCB containing 0.1% BSA and 1 mM Ca^{2+}) at 1 ml/min with or without test substance. The fluorescence emitted by excitation at 340 nm was directed through the video port of the microscope onto a

440 nm dichroic mirror and fluorescence intensity at 495 and 405 nm collected by photomultiplier tubes. The outputs from the photomultiplier tubes were amplified, digitized, and stored in an 80386 PC. Ratios of fluorescence intensity were
5 used to estimate $[Ca^{2+}]_i$.

(e) Measuring $[Ca^{2+}]_i$ in Oocytes

Additional studies used *Xenopus* oocytes injected with mRNA from bovine or human parathyroid cells and measured Cl^-
10 current as an indirect means of monitoring increases in $[Ca^{2+}]_i$. The following is an example of such studies used to test the effect of neomycin.

Oocytes were injected with poly(A)⁺-enriched mRNA from human parathyroid tissue (hyperplastic glands from a case of
15 secondary HPT). After 3 days, the oocytes were tested for their response to neomycin. Neomycin B evoked oscillatory increases in the Cl^- current which ceased upon superfusion with drug-free saline (see Fig. 20). Responses to neomycin B were observed at concentrations between 100 μ M and 10 mM.

20 To ensure that the response evoked by neomycin B was contingent upon injection of parathyroid mRNA, the effect of neomycin B on currents in water-injected oocytes was determined. In each of five oocytes examined, neomycin B (10 mM) failed to cause any change in the current.

25 About 40% of oocytes are known to respond to carbachol, an effect mediated by an endogenous muscarinic receptor. In five oocytes examined one showed inward currents in response to carbachol and this is shown in the lower trace of Fig. 20. Thus, in cells expressing a muscarinic receptor coupled to
30 increases in $[Ca^{2+}]_i$ and Cl^- current, neomycin B fails to evoke a response. This shows that the response to neomycin B depends on expression of a specific protein encoded by parathyroid cell mRNA. It strongly suggests that in intact

cells, neomycin B acts directly on the calcium receptor to alter parathyroid cell function.

(f) Measurement of PTH Secretion

5 In most experiments, cells loaded with fura-2 were also used in studies of PTH secretion. Loading parathyroid cells with fura-2 does not change their PTH secretory response to extracellular Ca^{2+} .

PTH secretion was measured by first suspending cells in
10 PCB containing 0.5 mM CaCl_2 and 0.1% BSA. Incubations were performed in plastic tubes (Falcon 2058) containing 0.3 ml of the cell suspension with or without small volumes of CaCl_2 and/or organic polycations. After incubation at 37°C for various times (typically 30 minutes), the tubes were placed
15 on ice and the cells pelleted at 2°C. Samples of the supernatant were brought to pH 4.5 with acetic acid and stored at -70°C. This protocol was used for both bovine and human parathyroid cells.

For bovine cells, the amount of PTH in sample
20 supernatants was determined by a homologous radioimmunoassay using GW-1 antibody or its equivalent at a final dilution of 1/45,000. ^{125}I -PTH (65-84; INCSTAR, Stillwater, MN) was used as tracer and fractions separated by dextran-activated charcoal. Counting of samples and data reduction were
25 performed on a Packard Cobra 5005 gamma counter.

For human cells, a commercially available radioimmunoassay kit (INS-PTH; Nichols Institute, Los Angeles, CA) which recognizes intact and N-terminal human PTH was used because GW-1 antibody recognizes human PTH poorly.
30

(g) Measurement of cyclic AMP

This section describes measuring cyclic AMP levels. Cells were incubated as above for PTH secretion studies and at the end of the incubation, a 0.15-ml sample was taken and

transferred to 0.85 ml of hot (70°C) water and heated at this temperature for 5-10 minutes. The tubes were subsequently frozen and thawed several times and the cellular debris sedimented by centrifugation. Portions of the supernatant
5 were acetylated and cyclic AMP concentrations determined by radioimmunoassay.

(h) Measurement of Inositol Phosphate Formation

This section describes procedures measuring inositol
10 phosphate formation. Membrane phospholipids were labeled by incubating parathyroid cells with 4 $\mu\text{Ci/ml}$ ^3H -myo-inositol for 20-24 hours. Cells were then washed and resuspended in PCB containing 0.5 mM CaCl_2 and 0.1% BSA. Incubations were performed in microfuge tubes in the absence or presence of
15 various concentrations of organic polycation for different times. Reactions were terminated by the addition of 1 ml chloroform-methanol-12 N HCl (200:100:1; v/v/v). Aqueous phytic acid hydrolysate (200 μl ; 25 μg phosphate/tube). The tubes were centrifuged and 600 μl of the aqueous phase was
20 diluted into 10 ml water.

Inositol phosphates were separated by ion-exchange chromatography using AG1-X8 in either the chloride- or formate-form. When only IP_3 levels were to be determined, the chloride-form was used, whereas the formate form was used
25 to resolve the major inositol phosphates (IP_3 , IP_2 , and IP_1). For determination of just IP_3 , the diluted sample was applied to the chloride-form column and the column was washed with 10 ml 30 mM HCl followed by 6 ml 90 mM HCl and the IP_3 was eluted with 3 ml 500 mM HCl. The last eluate was diluted and
30 counted. For determination of all major inositol phosphates, the diluted sample was applied to the formate-form column and IP_1 , IP_2 , and IP_3 eluted sequentially by increasing concentrations of formate buffer. The eluted samples from

the formate columns were rotary evaporated, the residues brought up in cocktail, and counted.

The isomeric forms of IP_3 were evaluated by HPLC. The reactions were terminated by the addition of 1 ml 0.45 M perchloric acid and stored on ice for 10 minutes. Following centrifugation, the supernatant was adjusted to pH 7-8 with $NaHCO_3$. The extract was then applied to a Partisil SAX anion-exchange column and eluted with a linear gradient of ammonium formate. The various fractions were then desalted with Dowex followed by rotary evaporation prior to liquid scintillation counting in a Packard Tri-carb 1500 LSC.

For all inositol phosphate separation methods, appropriate controls using authentic standards were used to determine if organic polycations interfered with the separation. If so, the samples were treated with cation-exchange resin to remove the offending molecule prior to separation of inositol phosphates.

2. Use of Lead Molecules

By systematically measuring the ability of a lead molecule to mimic or antagonize the effect of extracellular Ca^{2+} , the importance of different functional groups for calcimimetics and calcilytics were identified. Of the molecules tested, some are suitable as drug candidates while others are not necessarily suitable as drug candidates. The suitability of a molecule as a drug candidate depends on factors such as efficacy and toxicity. Such factors can be evaluated using standard techniques. Thus, lead molecules can be used to demonstrate that the hypothesis underlying calcium receptor-based therapies is correct and to determine the structural features that enable the calcium receptor-modulating agents to act on the calcium receptor and, thereby, to obtain other molecules useful in this invention.

Examples of molecules useful as calcimimetics include branched or cyclic polyamines, positively charged polyamino acids, and arylalkylamines. In addition, other positively charged organic molecules, including naturally occurring molecules and their analogues, are useful calcimimetics. These naturally occurring molecules and their analogues preferably have positive charge-to-mass ratios that correlate with those ratios for the molecules exemplified herein. (Examples include material isolated from marine species, arthropod venoms, terrestrial plants and fermentation broths derived from bacteria and fungi.) It is contemplated that one group of preferred naturally occurring molecules and analogues useful as calcimimetics will have a ratio of positive charge: molecular weight (in daltons) from about 1:40 to 1:200, preferably from about 1:40 to 1:100.

Fig. 36 provides additional examples of molecules expected to act as either calcilytics or calcimimetics based upon their structure. In general these molecules were synthesized based on the lead molecule, fendiline, and tested to determine their respective EC_{50} or IC_{50} values. Studies of stereoisomers, such as NPS 447 (R-fendiline) and NPS 448 (S-fendiline), have revealed stereospecific effects of molecular structure. The most active compounds tested to date are designated NPS R-467, NPS R-568, compound 8J, compound 8U, compound 9R, compound 11X, compound 12U, compound 12V, compound 12Z, compound 14U, compound 17M, compound 17P and compound 17X (see Table, *infra*). These compounds all have EC_{50} values of less than 5 μ M at the parathyroid cell calcium receptor.

The examples described herein demonstrate the general design of molecules useful as ionomimetics and ionolytics, preferably, calcimimetics and calcilytics. The examples also describe screening procedures to obtain additional molecules, such as the screening of natural product libraries. Using

5

This section describes useful functional groups for conferring increased mimetic or lytic activity and analytical procedures which can be used to identify different functional groups from lead molecules. Analysis of lead molecules have identified useful functional groups such as aromatic groups, stereospecificity (*R*-isomer) and preferred charge-to-molecule weight ratios. The described analytic steps and analogous analyses can be conducted on other lead molecules to obtain calcium receptor-modulating agents of increasing activity.

These results raised the question of whether positive charge alone determines potency, or if there are other structural features contributing to activity on the calcium receptor. This was important to determine at the outset because of its impact on the view that the calcium receptor can be targeted with effective and specific therapeutic molecules. Thus, a variety of other organic polycations related to neomycin B and spermine were studied to determine the relationship between the net positive charge of a molecule and its potency to mobilize intracellular Ca^{2+} .

The first series of molecules studied were the aminoglycosides. The ability of these molecules to mobilize

intracellular Ca^{2+} was determined in bovine parathyroid cells. The rank order of potency for eliciting cytosolic Ca^{2+} transients was neomycin B ($\text{EC}_{50} = 20$ or $40 \mu\text{M}$) > gentamicin ($150 \mu\text{M}$) > bekanamycin ($200 \mu\text{M}$) > streptomycin
 5 ($600 \mu\text{M}$). Kanamycin and lincomycin were without effect when tested at a concentration of $500 \mu\text{M}$. The net positive charge on these aminoglycosides at pH 7.3 is neomycin B (+6) > gentamicin (+5) = bekanamycin (+5) > kanamycin (average +4.5) > streptomycin (+3) > lincomycin (+1). Thus, within the
 10 aminoglycoside series there is some correlation between net positive charge and calcium receptor-modulating activity. However, the correlation is not absolute as illustrated by kanamycin, which would be predicted to be more potent than streptomycin, having no activity.

15 Testing of various polyamines revealed additional and more marked discrepancies between net positive charge and potency. Three structural classes of polyamines were examined: (1) straight-chain, (2) branched-chain, and (3) cyclic. The structures of the polyamines tested are provided
 20 in Fig. 1. Amongst the straight-chain polyamines, spermine (+4; $\text{EC}_{50} = 150 \mu\text{M}$) was more potent than pentaethylenhexamine (+6; $\text{EC}_{50} = 500 \mu\text{M}$) and tetraethylenepentamine (+5; $\text{EC}_{50} = 2.5 \text{ mM}$), even though the latter molecules have a greater net positive charge.

25 Branched-chain polyamines having different numbers of secondary and primary amino groups and, thus, varying in net positive charge were synthesized and tested. Two of these molecules, NPS 381 and NPS 382, were examined for effects on $[\text{Ca}^{2+}]_i$ in bovine parathyroid cells. NPS 382 (+8; $\text{EC}_{50} = 50$
 30 μM) was about twice as potent as NPS 381 (+10; $\text{EC}_{50} = 100 \mu\text{M}$), even though it contains two fewer positive charges.

A similar discrepancy between positive charge and potency was noted in experiments with cyclic polyamines. For example, hexacyclen (+6; $\text{EC}_{50} = 20 \mu\text{M}$) was more potent than

NPS 383 (+8; $EC_{50} = 150 \mu M$). The results obtained with these polyamines show that positive charge is not the sole factor contributing to potency.

Additional studies provided insights into other structural features of molecules that impart activity on the parathyroid cell calcium receptor. One of the structurally important features is the intramolecular distance between the nitrogens (which carry the positive charge). Spermine is 50-fold more potent than triethylenetetramine ($EC_{50} = 8 mM$) in evoking increases in $[Ca^{2+}]_i$ in bovine parathyroid cells, yet both molecules carry a net positive charge of +4. The only difference in structure between these two polyamines is the number of methylenes separating the nitrogens: in spermine it is 3-4-3 whereas in triethylenetetramine it is 2-2-2. This seemingly minor change in the spacing between nitrogens has profound implications for potency and suggests that the conformational relationships of nitrogens within the molecule are important.

Studies with hexacyclen and pentaethylenehexamine further demonstrated the importance of the conformational relationship. The former molecule is simply the cyclic analog of the latter and contains the same number of methylenes between all nitrogens, yet the presence of the ring structure increases potency 25-fold. These results indicate that positive charge *per se* is not the critical factor determining the activity of an organic molecule on the calcium receptor.

Another series of experiments revealed the importance of aromatic groups in determining activity on the calcium receptor. The initial results were obtained using two arylalkyl polyamines isolated from the venom of the spider *Argiope lobata*. These molecules, argiotoxin 636 and argiotoxin 659, have identical polycationic portions linked to different aromatic groups (Fig. 1e). Argiotoxin 659

evoked transient increases in $[Ca^{2+}]$, in bovine parathyroid cells when tested at concentrations of 100 to 300 μM . In contrast, argiotoxin 636 had no effect when tested at similar concentrations (Fig. 24). The only difference in structure
5 between these two arylalkyl polyamines is in the aromatic portion of the molecules: argiotoxin 659 contains a 4-hydroxyindole moiety whereas argiotoxin 636 contains a 2,4-dihydroxyphenyl group. The net positive charge on these two arylalkyl polyamines is the same (+4), so their different
10 potencies results from the different aromatic groups. This findings further demonstrates that net positive charge alone does not determine potency and that aromatic groups contribute significantly to the ability of molecules to activate the calcium receptor.

15 Substitutions on aromatic rings also effect calcium receptor-modulating activity. Agatoxin 489 (NPS 017) and Agatoxin 505 (NPS 015) both cause the mobilization of intracellular Ca^{2+} in parathyroid cells with EC_{50} 's of 6 and 22 μM , respectively. The only difference between the
20 structures of these molecules is a hydroxyl group on the indole moiety (Fig. 1f).

Thus, the structural features to be varied systematically from lead molecules described herein include the following: (1) net positive charge; (2) number of
25 methylenes separating nitrogens; (3) cyclic versions of molecules, for example polyamines with and without changes in methylene spacing and net positive charge; and (4) the structure and location of aromatic groups.

A variety of arylalkyl polyamines can be isolated from
30 the venoms of wasps and spiders. Additionally, analogous synthetic molecules can be prepared by the coupling of commercially available aromatic moieties to the argiotoxin polyamine moiety. The argiotoxin polyamine moiety can be

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readily coupled to any aromatic moiety containing a carboxylic acid.

One of ordinary skill in the art can readily obtain and systematically screen the hydroxy and methoxy derivatives of phenylacetic acid and benzoic acid as well as the hydroxyindoleacetic acid series using the techniques described herein. Analogues containing heteroaromatic functionalities can also be prepared and assessed for activity. Comparisons of potency and efficacy among molecules having different functional groups will reveal the optimal structure and location of the aromatic group at a constant positive charge.

(b) Testing of Natural Products

Testing of natural products and product libraries can be carried out to identify functional groups and to test molecules having particular functional groups. Screening of natural products selected on the basis of the structural information can be readily performed using the structure-function relationships established by the testing of lead molecules. For example, molecules can be selected on the basis of well-established chemotaxonomic principles using appropriate data bases, such as Napralert, to obtain pools of molecules having desired functional groups. For example, macrocyclic polyamine alkaloids derived from papilionoid legumes related to *Albizia*, such as *Pithecolobium*, and other plant-derived molecules can be screened.

The results obtained with budmunchiamine A illustrate the predictive power of the structure-activity studies and the novel structural information to be gained by testing natural products. One of the structural variations on the polyamine motif that seems to increase potency is the presence of the cyclic version of the straight-chain parent molecule. Budmunchiamine A, isolated from the plant *Albizia*

amara, is a cyclic derivative of spermine (Fig. 1a). The addition of budmunchiamine A to bovine parathyroid cells caused a rapid and transient increase in $[Ca^{2+}]_i$ that persisted in the absence of extracellular Ca^{2+} and was
5 blunted by pretreatment with PMA. It therefore causes the mobilization of intracellular Ca^{2+} in parathyroid cells, probably by acting on the calcium receptor. It is about equipotent with spermine (EC_{50} about 200 μM), yet carries one less positive charge (+3) than does spermine.

10

3. Polyamines

Preferred polyamines useful as calcimimetics in this invention may be either branched or cyclic. Branched or cyclic polyamines potentially have higher calcimimetic
15 activity than their straight-chain analogues. That is, branched or cyclic polyamines tend to have a lower EC_{50} than their corresponding linear polyamines with the same effective charge at physiological pH (see Table 1).

Table 1

Molecule	Net (+) Charge	EC ₅₀ (μM)
5 Neomycin	+6	20 or 40
Hexacyclen	+6	20
NPS 382	+8	50
NPS 381	+10	100
NPS 383	+8	150
10 Gentamicin	+5	150
Spermine	+4	150
Bekanamycin	+5	200
Argiotoxin-659	+4	300
Pentaethylenhexamine (PEHA)	+6	500
15 Streptomycin	+3	600
Spermidine	+3	2000
Tetraethylenepentamine (TEPA)	+5	2500
1,12-diaminododecane (DADD)	+2	3000
Triethylenetramine (TETA)	+4	8000

20

"Branched polyamines" as used herein refers to a chain molecule consisting of short alkyl bridges or alkyl groups joined together by amino linkages, and also containing points at which the chain branches. These "branch points" can be located at either a carbon atom or a nitrogen atom, preferably at a nitrogen atom. A nitrogen atom branch point is typically a tertiary amine, but it may also be quaternary. A branched polyamine may have 1 to 20 branch points, preferably 1 to 10 branch points.

30

Generally, the alkyl bridges and alkyl branches in a branched polyamine are from 1 to 50 carbon atoms in length, preferably 1-15, more preferably from 2 to 6 carbon atoms. The alkyl branches may also be interrupted by one or more heteroatoms (nitrogen, oxygen or sulfur) or substituted with

functional groups such as: halo, including fluoro, chloro, bromo, or iodo; hydroxy; nitro; acyloxy ($R'COO-$), acylamido ($R'CONH-$), or alkoxy ($-OR'$), where R' may contain from 1 to 4 carbon atoms. The alkyl branches may also be substituted
 5 with groups that are positively charged at physiological pH, such as amino or guanidino. These functional substituents may add or change physical properties such as solubility to increase activity, delivery or bioavailability of the molecules.

10 The branched polyamines may have three or more chain and branch termination points. These termination points may be methyl groups or amino groups, preferably amino groups.

A preferred group of branched polyamines have the formula:

15



where k is an integer from 1 to 10;

each j is the same or different and is an integer from
 20 2 to 20;

each R_i is the same or different and is selected from the group consisting of hydrogen and $-(CH_2)_j-NH_2$, where j is as defined above; and

at least one R_i is not hydrogen.

25 Particularly preferred branched polyamines of this invention are the molecules $N^1, N^1, N^5, N^{10}, N^{14}, N^{14}$ -hexakis-(3-aminopropyl) spermine and $N^1, N^1, N^5, N^{14}, N^{14}$ -tetrakis-(3-aminopropyl)spermine referred to as NPS 381 and NPS 382, respectively, in Figures 1a and 1f.

30 "Cyclic polyamines" refers to heterocycles containing two or more heteroatoms (nitrogen, oxygen or sulfur), at least two of which are nitrogen atoms. The heterocycles are generally from about 6 to about 20 atoms in circumference, preferably from about 10 to about 18 atoms in circumference.

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The nitrogen heteroatoms are separated by 2 to 10 carbon atoms. The heterocycles may also be substituted at the nitrogen sites with aminoalkyl or aminoaryl groups ($\text{NH}_2\text{R}-$), wherein R is aminoaryl or a lower alkyl of 2 to 6 carbon atoms. Particularly preferred cyclic polyamines of this invention are shown in Figures 1f and 1a as hexacyclen (1,4,7,10,13,16-hexaaza-cyclooctadecane) and NPS 383.

4. Polyamino Acids

10 "Polyamino acids" refers to polypeptides containing two or more amino acid residues which are positively charged at physiological pH. Positively charged amino acids include histidine, lysine and arginine. The polyamino acids can vary
15 in length from 2 to 800 amino acids, more preferably from 20 to 300 amino acids and may consist of a single repeating amino acid residue or may have the variety of a naturally occurring protein or enzyme. Preferred polyamino acids are polyarginine, polylysine, and poly(argininyl-tyrosine), having 20-300 residues, and protamine or a protamine analog.

20 The amino acid residues present in the polyamino acids may be any of the twenty naturally occurring amino acids, or other alternative residues. Alternative residues include, for example, the ω -amino acids of the formula $\text{H}_2\text{N}(\text{CH}_2)_n\text{COOH}$, where n is from 2 to 6, and other nonpolar amino acids, such
25 as sarcosine, t-butyl alanine, t-butyl glycine, N-methyl isoleucine, norleucine, phenyl glycine, citrulline, methionine sulfoxide, cyclohexyl alanine, and hydroxyproline. Ornithine is an example of an alternative positively charged amino acid residue. The polyamino acids of this invention
30 may also be chemically derivatized by known methods.

5. Arylalkyl Polyamines

"Arylalkyl polyamines" refers to a class of positively charged natural products derived from arthropod venoms. Preferred arylalkyl polyamines are philanthotoxin-433, argiotoxin-636, argiotoxin-659, agatoxin 505, agatoxin 489 (Figure 1), and analogous synthetic molecules modeled after these natural products.

6. Arylalkyl Amines

Preferred molecules of the present invention are arylalkyl amines having structure I; more preferably having structure III described *supra*, wherein R_1 is an aryl group, preferably a carbocyclic aryl group such as phenyl or a bicyclic carbocyclic aryl groups such as naphthyl, preferably 1-naphthyl. Especially preferred are *R*-isomers.

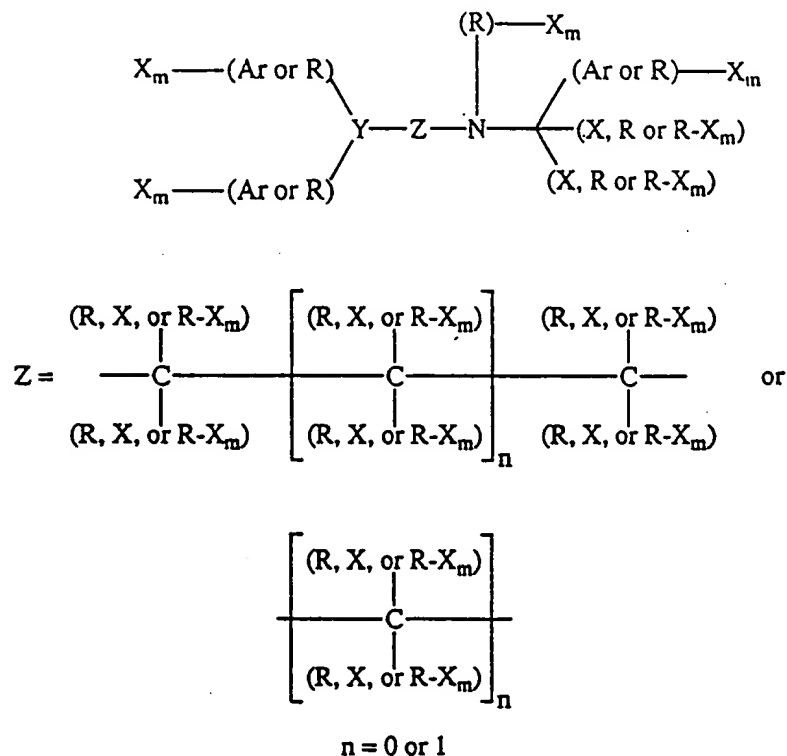
Two examples of arylalkyl amines are NPS 467 and NPS 568. NPS 467 and NPS 568 are analogues. NPS 568 is more potent in causing increases in $[Ca^{2+}]_i$ in bovine and human parathyroid cells than NPS 467. The effects of NPS 568 and NPS 467 are stereospecific and it is the *R*-isomer that is the more potent enantiomer (see Table 6, *infra*). NPS *R*-568 is at present the lead calcimimetic compound with selective activity at the parathyroid cell calcium receptor.

NPS *R*-568 behaves, albeit with greater potency, similarly to NPS *R*-467. NPS *R*-568 evokes increases in $[Ca^{2+}]_i$ in bovine parathyroid cells in a stereospecific manner (see Table 6, *infra*). NPS *R*-568 fails to evoke increases in $[Ca^{2+}]_i$ in the absence of extracellular Ca^{2+} , but it does potentiate responses to extracellular Ca^{2+} . NPS *R*-568 shifts the concentration-response curve for extracellular Ca^{2+} to the left.

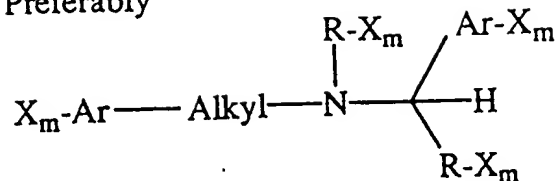
The oral administration of NPS *R*-568 to rats causes a dose-dependent decrease in the levels of serum Ca^{2+} ($ED_{50} = 7$ mg/kg). The hypocalcemic response elicited by the oral

administration of NPS R-568 is rapid in onset and is paralleled by decreases in the levels of serum PTH. The hypocalcemic response evoked by the oral administration of NPS R-568 is only marginally affected by prior complete nephrectomy. However, NPS R-568 fails to elicit a hypocalcemic response in parathyroidectomized rats. NPS R-568 can thus target selectively the parathyroid cell calcium receptor *in vivo* and cause an inhibition of PTH secretion. The decreases in serum levels of PTH together with the resulting hypocalcemia are desirable therapeutic effects in cases of hyperparathyroidism.

Also preferred are arylalkyl amines having the structure:



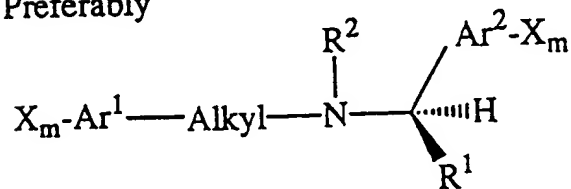
More Preferably



Alkyl = C₁-C₆ cyclic, preferably linear, or more preferably branched hydrocarbon (sp² or preferably sp³ hybridization)

Ar = (preferably) phenyl, 1-, or 2-naphthyl

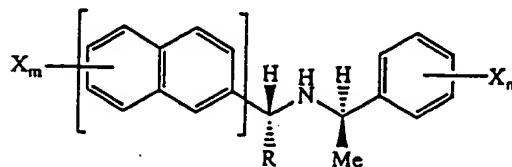
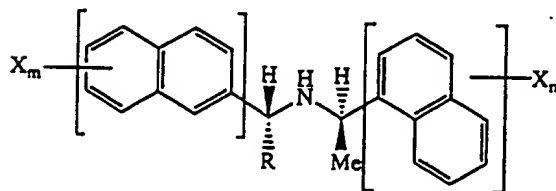
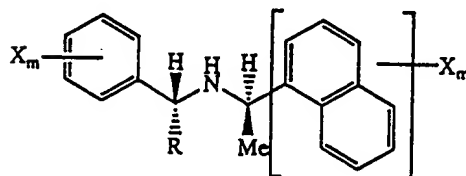
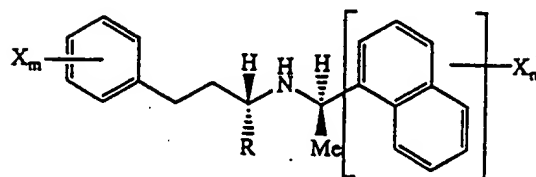
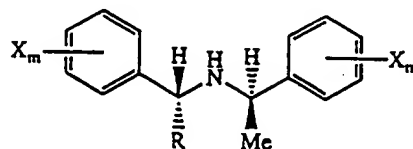
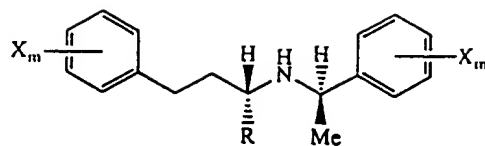
More Preferably



Alkyl = C₁-C₆ cyclic, preferably linear, or more preferably branched hydrocarbon (sp² or preferably sp³ hybridization).

Ar¹ = (preferably) phenyl or 2-naphthyl; Ar² (preferably) = phenyl or 1-naphthyl. R¹ = (preferably) methyl, R² = (preferably) H

Most Preferably



More Preferably $R = C_1-C_3$,
Most Preferably $R = Me$

X = nothing; for example when C (Carbon, see Z =) are sp^2 or sp^1 , or for example when Y = O (Oxygen). Possible combinations are not limited to these examples.

X = -H

X = -F, -Cl, -Br, or -I

X = -OR

X = -NR₂ (R's selected independently)

X = -SR, S(O)R, S(O)₂R,

X = -CN

X = -NO₂

X = -C(O)R -OC(O)R, -C(O)OR -NRC(O)R, C(O)NR₂, (R's selected independently)

R = -H, -CF₃, -CF₂H, -CFH₂, -CH₂CF₃, -C₁-C₁₀ (sp , sp^2 , or sp^3 carbons, selected independently) alkyl (linear, branched, cyclic system, fused cyclic or bicyclic systems, selected independently) or phenyl.

Ar = any aromatic, heteroaromatic, or heterocyclic system, preferably phenyl, 1-naphthyl, 2-naphthyl, biphenyl, tetrahydronaphthyl, indanyl, indenyl, fluorenyl, 9,10-dihydranthracenyl, 9,10-dihydrophenanthrenyl, pyrrolyl, furanyl, 1,2,3-triazolyl, 1,2,4-triazolyl, tetrazolyl, imidazolyl, oxazolyl, thiazolyl, pyrazolyl, thiofuranyl, isoxazolyl, pyridinyl, pyridazinyl, pyrimidinyl, pyrazinyl, 1,2,4-triazinyl, 1,3,5-triazinyl, tetrahydrofuranyl, pyrrolidinyl, imidazolinyl, thiazolidinyl, decahydroquinolinyl, decahydroisoquinolinyl, piperidinyl, piperizinyl, morpholinyl, thiomorpholinyl, benzofuranyl, dihydrobenzofuranyl, dihydrobenzopyranyl, benzimidazolyl, indazolyl, tetrahydroquinolinyl, tetrahydroisoquinoline, quinolinyl, isoquinolinyl, benzotriazolyl, carbazolyl, indolyl, indolinyl, phenoxazinyl, phenothiazinyl, α -carbolinyl, β -carbolinyl, acenaphthenyl, or acenaphthylenyl.

Y = -NR, -O, -S, -S(O), -S(O)₂, -C^{*}R, -C^{*}(O), -OC^{*}(O), -C^{*}(O)O, -NRC^{*}(O), C^{*}(O)NR, (^{*} sp^2 carbon), -CR₂, -CRX, or -CX₂.

m = 1 through 7 inclusive (independent).

Z and N together form a piperidinyl, piperazinyl or pyrrolinyl ring.

7. Additional Components

Calcium receptor-modulating agents may be substituted with additional components. The additional components are used to provide additional functionality to the molecules, apart from the molecules' ability to act as a calcimimetic or calcilytic. These additional components include targeting components and functionalities such as labels which enhance a molecule's ability to be used in the different applications, such as for screening for agonists or antagonists of extracellular Ca^{2+} in a competitive or non-competitive assay format.

For example, an immunoglobulin or a ligand specific for parathyroid cells or a calcium receptor can be used as a target-specific component. The immunoglobulin can be a polyclonal or monoclonal antibody and may comprise whole antibodies or immunologically reactive fragments of these antibodies such as $\text{F}(\text{ab},)$, $\text{F}(\text{ab})$, or $(\text{F}_{\text{ab}})_2$.

A wide variety of labeling moieties can be used, including radioisotopes, chromophores, and fluorescent labels. Radioisotope labeling in particular can be readily detected *in vivo*. Radioisotopes may be coupled by coordination as cations in the porphyrin system. Useful cations include technetium, gallium, and indium. In the compositions, the positively charged molecule can be linked to or associated with a label.

II. SYNTHESIS OF CALCIUM RECEPTOR-MODULATING AGENTS

Different ionomimetics and ionolytics can be synthesized by using procedures known in the art and described herein. Ionomimetics and ionolytics can also be synthesized as described by Bradford C VanWagenen, Steven R Duff, William A. Nelson and Thomas E. D'Ambra in U.S. Patent Application, entitled "Amine Preparation" hereby incorporated by reference herein.

A. Synthesis of Polyamines

The synthetic methods used to produce polyamines described in this section are modelled after methods used to construct argiopines 636 and 659 and other arylalkyl polyamines derived from spider venoms. Polyamines can be synthesized starting with, for example, diaminoalkanes and simple polyamines such as spermidine or spermine. Strategies for the synthesis and the modification of polyamines involve using a variety of amine-protecting groups (e.g., phthalimido, BOC, CBZ, benzyl, and nitrile) which can be selectively removed to construct functionalized molecules.

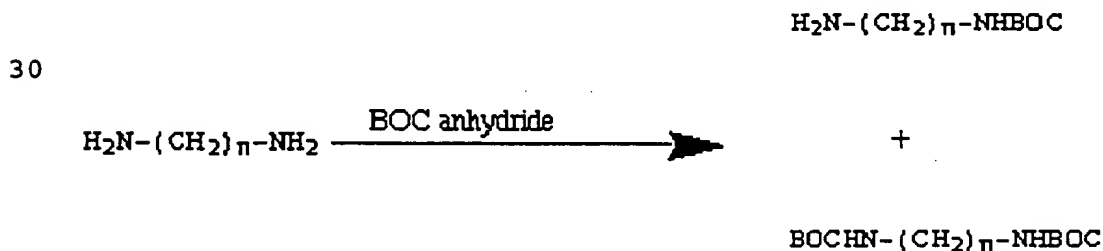
Chain extensions, of the starting material, by 2-4 methylenes were typically accomplished by alkylation with the corresponding N-(bromoalkyl)phthalimide. A 1:1.2 mixture of amine to the bromoalkylphthalimide was refluxed in acetonitrile in the presence of 50% KF on Celite. Chain extensions were also accomplished by alkylation of a given amine with acrylonitrile or ethylacrylate. Reaction progress was monitored by thin-layer chromatography (TLC) and intermediates purified on silica gel using combinations of dichloromethane, methanol, and isopropylamine. Final products were purified by cation exchange (HEMA-SB) and RP-HPLC (Vydac C-18). Purity and structure verification were accomplished by ^1H - and ^{13}C -NMR spectroscopy and high-resolution mass spectrometry (EI, CI and/or FAB).

Amine-protecting groups, phthalimido, BOC, CBZ, benzyl, and nitrile, were added and later selectively removed to construct functionalized molecules. BOC protecting groups were added by treating a primary or secondary amine (1° or 2°) with di-tert-butyl dicarbonate in dichloromethane. Benzyl protecting groups were applied in one of two ways: (1) condensation of a 1° amine with benzaldehyde followed by sodium borohydride reduction or (2) alkylation of a 2° amine with benzylbromide in the presence of KF.

Deprotection of the different groups was carried out using different procedures. Deprotection of the phthalimido functionality was accomplished by reduction with hydrazine in refluxing methanol. Deprotection of the BOC functionality was accomplished in anhydrous TFA or concentrated HCl in acetonitrile. Deprotection of benzyl, nitrile, and CBZ protecting functionalities was accomplished by reduction in glacial acetic acid under 55 psi hydrogen in the presence of a catalytic amount of palladium hydroxide on carbon. Nitrile functionalities in the presence of benzyl and CBZ groups were selectively reduced under hydrogen in the presence of sponge Raney nickel.

Amide linkages were typically prepared by reacting an amine (1° or 2°) with an *N*-hydroxysuccinimide or *p*-nitrophenylester of a given acid. This was accomplished directly, in the case of adding cyclic groups, by treating the amine with dicyclohexylcarbodiimide under dilute conditions.

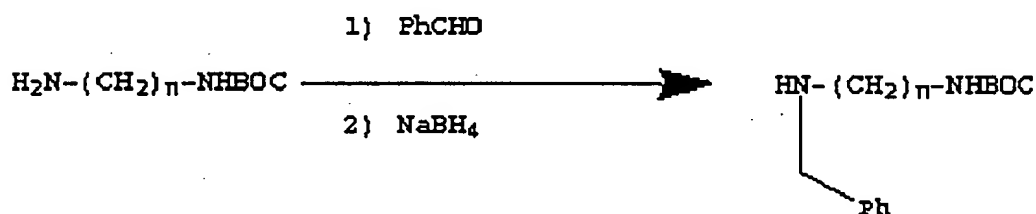
Specifically, branched polyamines are typically prepared from simple diaminoalkanes of the formula $\text{NH}_2-(\text{CH}_2)_n-\text{NH}_2$, or simple polyamines such as spermidine or spermine. One of the two primary (terminal) amines is protected or "masked" with a protecting group such as BOC (*t*-butyloxycarbonyl), phthalimido, benzyl, 2-ethylnitrile (the Michael condensation product of an amine and acrylonitrile), or amide. A typical reaction is the addition of a BOC protecting group by treatment with di-*t*-butyl-dicarbonate (BOC anhydride):



The monoprotected product is separated from the unprotected and diprotected products by simple chromatographic or distillation techniques.

The remaining free amine in the monoprotected product is then selectively alkylated (or acylated) with an alkylating (or acylating) agent. To ensure mono-alkylation, the free amine is partially protected by condensation with benzaldehyde followed by sodium borohydride reduction to form the N-benzyl derivative:

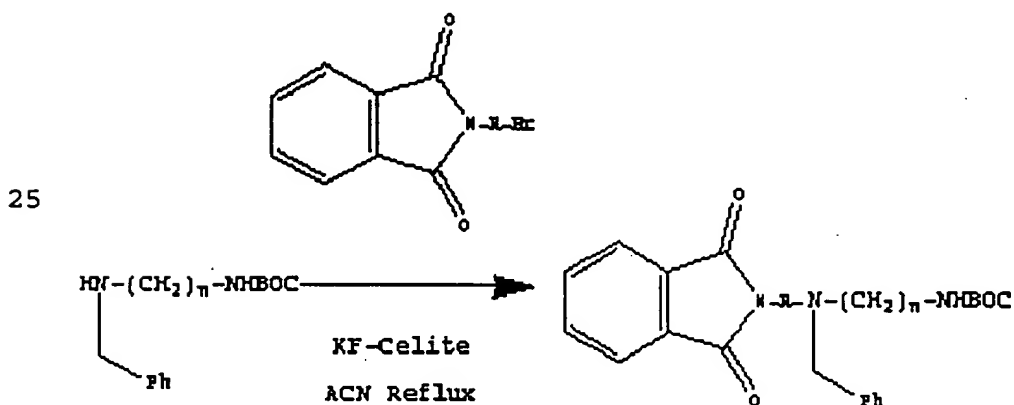
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The N-benzyl derivative is then reacted with the alkylating agent. A typical alkylating agent is in an N-(bromoalkyl)phthalimide, which reacts as follows:

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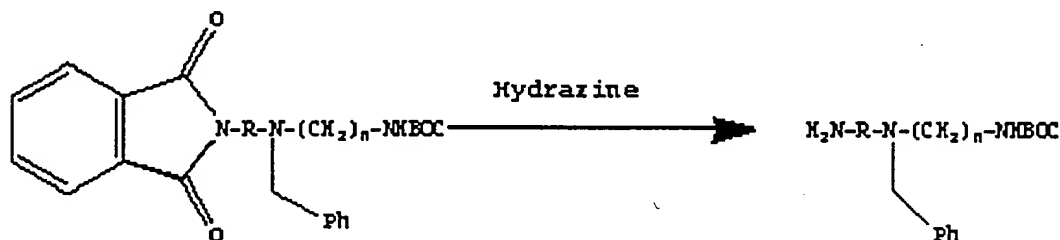


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For example, N-(bromobutyl)phthalimide is used to extend or branch the chain with four methylene units. Alternatively, reaction with acrylonitrile followed by reduction of the cyano group will extend the chain by three methylenes and an amino group.

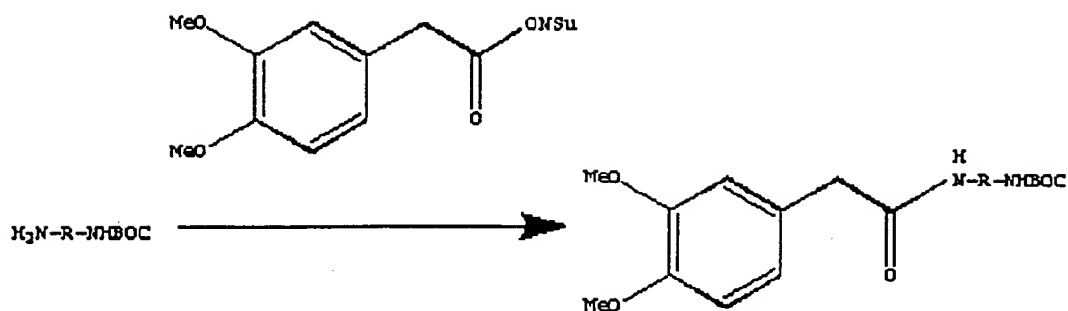
The protecting groups of the resulting chain-extended molecule can then be selectively cleaved to yield a new free amine. For example, trifluoroacetic acid is used to remove a BOC group; catalytic hydrogenation is used to reduce a nitrile functionality and remove a benzyl group; and hydrazine is used to remove phthalimido groups as follows:



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The new free amine may be alkylated (or acylated) further as above to increase the length of the polyamine. This process is repeated until the desired chain length and number of branches is obtained. In the final step, deprotection of the product results in the desired polyamine. However, further modifications may be effected at the protected end prior to deprotection. For example, prior to BOC-deprotection, the polyamine is acylated with the N-hydroxysuccinimide ester of 3,4-dimethoxyphenylacetic acid to yield a diprotected polyamine:

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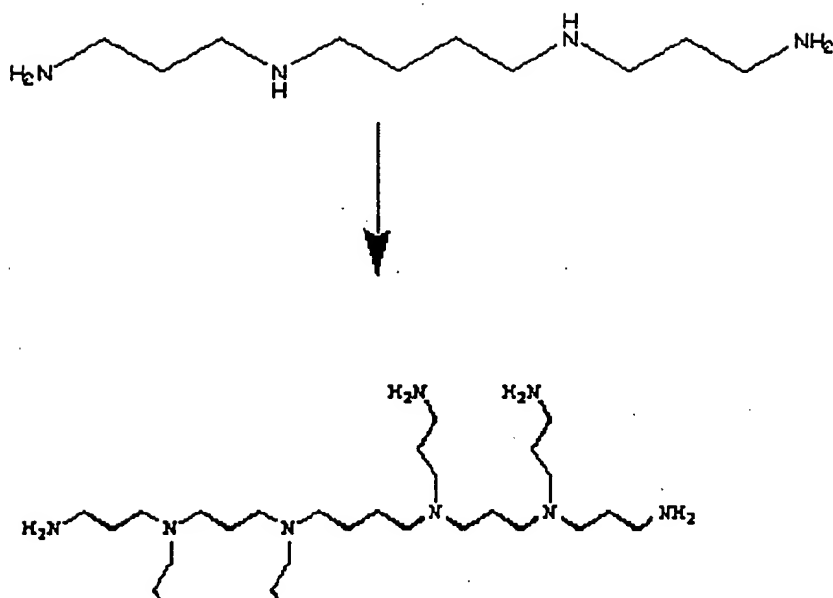
5

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This ultimately yields an arylalkyl polyamine. The BOC group can then be selectively removed with trifluoroacetic acid to expose the other amino terminus which can be extended as above.

Certain branched polyamines may be formed by simultaneously alkylating or acylating the free primary and secondary amines in a polyamine formed as above. For example, treatment of spermine with excess acrylonitrile followed by catalytic reduction yields the following:

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Cyclic polyamines may be prepared as above with starting materials such as hexacylen (Aldrich Chem.).

B. Polyamino Acid Synthesis

- 15 Polyamino acids can be made using standard techniques such as being translated using recombinant nucleic acid techniques or being synthesized using standard solid-phase techniques. Solid-phase synthesis is commenced from the carboxy-terminal end of the peptide using an α -amino

protected amino acid. BOC protective groups can be used for all amino groups even through other protective groups are suitable. For example, BOC-lys-OH can be esterified to chloromethylated polystyrene resin supports. The polystyrene resin support is preferably a copolymer of styrene with about 0.5 to 2% divinylbenzene as a cross-linking agent which causes the polystyrene polymer to be completely insoluble in certain organic solvents. See Stewart et al., Solid-Phase Peptide Synthesis (1969), W.H. Freeman Co., San Francisco; and Merrifield, J. Am. Chem. Soc. (1963) 85:2149-2154. These and other methods of peptide synthesis are also exemplified by U.S. Patent Nos. 3,862,925; 3,842,067; 3,972,859; and 4,105,602.

The polypeptide synthesis may use manual techniques or be automated. For example, synthesis can be carried out using an Applied Biosystems 403A Peptide Synthesizer (Foster City, California) or a Biosearch SAM II automatic peptide synthesizer (Biosearch, Inc., San Rafael, California), following the instructions provided in the instruction manual supplied by the manufacturer.

C. Arylalkyl Polyamines

Arylalkyl polyamines such as those shown in Figure 1 can be obtained from natural sources isolated by known techniques, or synthesized as described in Jasys et al., Tetrahedron Lett. 29:6223-6226, (1988); Nason et al., Tetrahedron Lett. 30:2337-2340, (1989); and Schafer et al., "Polyamine Toxins from Spiders and Wasps," The Alkaloids, vol. 45, p. 1-125, 1994.

D. Arylalkylamines

This section describes general protocol to prepare arylalkylamines such as fendiline or fendiline analogues as shown in Figure 36. In a 10-ml round-bottom flask equipped

with a magnetic stir bar and rubber septum, 1.0 mmole 3,3'-diphenylpropylamine (or primary alkylamine such as substituted or unsubstituted phenylpropylamine) in 2 ml ethanol was treated with 1.0 mmole acetophenone (or substituted acetophenone). Two millimoles MgSO_4 and 1.0 mmole NaCNBH_3 were then added and the solution was stirred under a nitrogen atmosphere at room temperature (about 20°C) for 24 hours. The reaction was poured into 50 ml ether and washed 3 times with 1 N NaOH and once with brine. The ether layer was dried with anhydrous K_2CO_3 and reduced in vacuo. The product was then purified by column chromatography or HPLC incorporating a silica stationary phase with combinations of CH_2Cl_2 -methanol-isopropylamine (typically 3% methanol and 0.1% isopropylamine in methylene chloride).

A preferred procedure for preparing fendiline or fendiline analogues (such as those depicted in Figure 36) uses titanium(IV) isopropoxide and was modified from methods described in J. Org. Chem. 55:2552 (1990). For the synthesis of Compound 2M, titanium tetrachloride (method described in Tetrahedron Lett. 31:5547 (1990)) was used in place of titanium(IV) isopropoxide.

A reaction scheme is depicted in Figure 43a. In Figure 43a, R, R' and R" depict appropriately substituted hydrocarbon and aromatic moieties groups. Referring to Figure 43a in a 4-ml vial, 1 mmole of amine (1) (typically a primary amine) and 1 mmole ketone or aldehyde (2) (generally an appropriately substituted acetophenone) are mixed, then treated with 1.25 mmoles titanium(IV) isopropoxide (3) and allowed to stand with occasional stirring at room temperature for about 30 minutes. Alternatively, a secondary amine may be used in place of (1). Reactions giving heavy precipitates or solids can be heated to their melting point to allow for mixing during the course of the reaction.

The reaction mixture is then treated with 1 ml ethanol containing 1 mmole sodium cyanoborohydride (4) and the resulting mixture is allowed to stand at room temperature with occasional stirring for about 16 hours. After this time
5 the reaction is quenched by the addition of about 500 μ l water. The reaction mixture is then diluted to about 4 ml total volume with ethyl ether and then centrifuged. The upper organic phase is removed and reduced on a rotavapor. The resulting product (6) is partially purified by
10 chromatography through a short silica column (or alternatively by using preparative TLC on silica) using a combination of dichloromethane-methanol-isopropylamine (typically 95:5:0.1), and then purified by HPLC (normal-phase using silica with dichloromethane-methanol-isopropylamine or
15 reversed phase, C-18 with 0.1% TFA with acetonitrile or methanol).

Chiral resolution may be accomplished using methods such as those described in Example 22, *infra*.

20 III. INORGANIC ION RECEPTORS, DERIVATIVES, AND FRAGMENTS

The invention also relates to a superfamily of inorganic ion receptor proteins including derivatives thereof, and inorganic ion receptor fragments. Members of the superfamily related to each other by similarity of amino acid sequence
25 and structure. Receptor proteins, such as the calcium receptor, have intracellular domains, extracellular domains, transmembrane domains, and multiple-transmembrane domains. Preferably, the novel superfamily of inorganic ion receptors have an amino acid sequence similarity of at least 15% to the
30 human calcium receptor (SEQ. ID. NOs. 6 and 7) and respond to inorganic ions.

Calcium receptors appear to be functionally related to a class of receptors which utilize so-called "G" proteins to couple ligand binding to intracellular signals. Such "G-

coupled" receptors may elicit increases in intracellular cyclic AMP due to the stimulation of adenylyl cyclase by a receptor activated "G_s" protein, or else may elicit a decrease in cyclic AMP due to inhibition of adenylyl cyclase by a receptor activated "G_i" protein. Other receptor activated G proteins elicit changes in inositol triphosphate levels resulting in release of Ca²⁺ from intracellular stores. This latter mechanism is particularly pertinent to calcium receptors.

10

A. Inorganic Ion Receptors

Inorganic ion receptors have an amino acid sequence encoding a functioning inorganic ion receptor. Inorganic ion receptors include proteins having the amino acid sequence of the receptor protein normally found in a cell and derivatives thereof. Inorganic ion receptors are distinguished by their ability to detect and respond to changes in the levels of inorganic ions by evoking a change in cellular function. Changes in cellular function may involve changes in secondary messenger levels such those mediated by G protein coupled to the receptor or changes in ionic transmembrane ion flux. Inorganic ions include cations such as calcium, magnesium, potassium, sodium, or hydrogen ions and anions such as phosphate or chloride ions. Cd²⁺ sensing receptors are described by Herbert in U.S. application entitled "Cloned Human Cadmium(II)-Sensing Receptor and Uses thereof," hereby incorporated by reference herein.

Regardless of the nature of the physiological ligand or activator of an inorganic ion receptor, inorganic ion receptors can be "promiscuous" in that they can be activated by non-physiological stimuli. These non-physiological stimuli may be useful, for example, to identify another inorganic ion receptor or to facilitate the isolation of the gene encoding it. An example of an inorganic ion receptor

"Cloned Human Cadmium(II)-Sensing Receptor and Uses thereof"

responding to a non-physiological stimuli is the ability of osteoclast calcium receptor to respond not only to Ca^{2+} , but also to Mn^{2+} , Co^{2+} and Ni^{2+} . The cations Mn^{2+} and Co^{2+} also serve to distinguish the osteoclast calcium receptor from the parathyroid calcium receptor.

Another example of an inorganic ion receptor responding to a non-physiological stimuli is the ability of the parathyroid calcium receptor to respond to low concentrations of La^{3+} and Gd^{3+} which are highly unlikely to be encountered under normal circumstances. Nevertheless, Gd^{3+} has been used successfully as an activator for the calcium receptor and facilitated the cloning of this receptor by expression in *Xenopus* oocytes (see Example 25).

Additionally, receptors belonging to the superfamily of inorganic ion receptors may also be activated by stimuli other than ligand binding. For example, some members are activated by physical forces such as stretch forces acting on membranes of cells expressing inorganic ion receptors.

B. Inorganic Ion Receptor Derivatives

Derivatives of a particular receptor have similar amino acid sequence and retain, to some extent, one or more activities of the related receptor. Derivatives have at least 15% sequence similarity, preferably 70%, more preferably 90%, even more preferably 95% sequence similarity to the related receptor. "Sequence similarity" refers to "homology" observed between amino acid sequences in two different polypeptides, irrespective of polypeptide origin.

The ability of the derivative to retain some activity can be measured using techniques described herein, for example, those described in Section I *supra*. Derivatives include modification occurring during or after translation, for example, by phosphorylation, glycosylation, crosslinking, acylation, proteolytic cleavage, linkage to an antibody

molecule, membrane molecule or other ligand (see Ferguson et al., 1988, Annu. Rev. Biochem. 57:285-320).

Specific types of derivatives also include amino acid alterations such as deletions, substitutions, additions, and amino acid modifications. A "deletion" refers to the absence of one or more amino acid residue(s) in the related polypeptide. An "addition" refers to the presence of one or more amino acid residue(s) in the related polypeptide. Additions and deletions to a polypeptide may be at the amino terminus, the carboxy terminus, and/or internal. Amino acid "modification" refers to the alteration of a naturally occurring amino acid to produce a non-naturally occurring amino acid. A "substitution" refers to the replacement of one or more amino acid residue(s) by another amino acid residue(s) in the polypeptide. Derivatives can contain different combinations of alterations including more than one alteration and different types of alterations.

While the effect of an amino acid change varies depending upon factors such as phosphorylation, glycosylation, intra-chain linkages, tertiary structure, and the role of the amino acid in the active site or a possible allosteric site, it is generally preferred that the substituted amino acid is from the same group as the amino acid being replaced. To some extent the following groups contain amino acids which are interchangeable: the basic amino acids lysine, arginine, and histidine; the acidic amino acids aspartic and glutamic acids; the neutral polar amino acids serine, threonine, cysteine, glutamine, asparagine and, to a lesser extent, methionine; the nonpolar aliphatic amino acids glycine, alanine, valine, isoleucine, and leucine (however, because of size, glycine and alanine are more closely related and valine, isoleucine and leucine are more closely related); and the aromatic amino acids phenylalanine, tryptophan, and tyrosine. In addition, although classified

5 While proline is a nonpolar neutral amino acid, its replacement represents difficulties because of its effects on conformation. Thus, substitutions by or for proline are not preferred, except when the same or similar conformational results can be obtained. The conformation conferring properties of proline residues may be obtained if one or more of these is substituted by hydroxyproline (Hyp).

Preferred derivatives have one or more amino acid alteration(s) which do not significantly affect the receptor activity of the related receptor protein. In regions of the calcium receptor protein not necessary for receptor activity amino acids may be deleted, added or substituted with less risk of affecting activity. In regions required for receptor activity, amino acid alterations are less preferred as there is a greater risk of affecting receptor activity. Such alterations should be conservative alterations. For example, one or more amino acid residues within the sequence can be substituted by another amino acid of a similar polarity which acts as a functional equivalent.

Conserved regions tend to be more important for protein activity than non-conserved regions. Standard procedures can be used to determine the conserved and non-conserved regions important of receptor activity using *in vitro* mutagenesis techniques or deletion analyses and measuring receptor activity as described by the present disclosure.

Derivatives can be produced using standard chemical techniques and recombinant nucleic acid techniques. Modifications to a specific polypeptide may be deliberate, as through site-directed mutagenesis and amino acid substitution during solid-phase synthesis, or may be accidental such as through mutations in hosts which produce the polypeptide. Polypeptides including derivatives can be obtained using standard techniques such as those described in Section I.G.2. *supra*, and by Sambrook et al., *Molecular Cloning*, Cold Spring Harbor Laboratory Press (1989). For example, Chapter 15 of Sambrook describes procedures for site-directed mutagenesis of cloned DNA.

20 C. Receptor Fragments

Receptor fragments are portions of inorganic ion receptors. Receptor fragments preferably bind to one or more binding agents which bind to a full-length receptor. Binding agents include ionomimetics, ionolytics, and antibodies which bind to the receptor. Fragments have different uses such as to select other molecules able to bind to a receptor.

Fragments can be generated using standard techniques such as expression of cloned partial sequences of receptor DNA and proteolytic cleavage of a receptor protein. Proteins are specifically cleaved by proteolytic enzymes, such as trypsin, chymotrypsin or pepsin. Each of these enzymes is specific for the type of peptide bond it attacks. Trypsin catalyzes the hydrolysis of peptide bonds whose carbonyl group is from a basic amino acid, usually arginine or lysine.

Pepsin and chymotrypsin catalyze the hydrolysis of peptide bonds from aromatic amino acids, particularly tryptophan, tyrosine and phenylalanine.

Alternate sets of cleaved protein fragments are
5 generated by preventing cleavage at a site which is susceptible to a proteolytic enzyme. For example, reaction of the ϵ -amino group of lysine with ethyltrifluorothioacetate in mildly basic solution yields a blocked amino acid residue whose adjacent peptide bond is no longer susceptible to
10 hydrolysis by trypsin. Goldberger et al., Biochemistry 1:401 (1962). Treatment of such a polypeptide with trypsin thus cleaves only at the arginyl residues.

Polypeptides also can be modified to create peptide linkages that are susceptible to proteolytic enzyme-catalyzed
15 hydrolysis. For example, alkylation of cysteine residues with β -haloethylamines yields peptide linkages that are hydrolyzed by trypsin. Lindley, Nature, 178: 647 (1956).

In addition, chemical reagents that cleave polypeptide chains at specific residues can be used. Witcop, Adv.
20 Protein Chem. 16: 221 (1961). For example, cyanogen bromide cleaves polypeptides at methionine residues. Gross & Witkip, J. Am. Chem. Soc. 83: 1510 (1961).

Thus, by treating an inorganic ion receptor, such as, for example, a human calcium receptor or fragments thereof,
25 with various combinations of modifiers, proteolytic enzymes and/or chemical reagents, numerous discrete overlapping peptides of varying sizes are generated. These peptide fragments can be isolated and purified from such digests by chromatographic methods. Alternatively, fragments can be
30 synthesized using an appropriate solid-state synthetic procedure.

Fragments may be selected to have desirable biological activities. For example, a fragment may include just a ligand binding site. Such fragments are readily identified

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Other useful fragments include those having only the external portion, membrane-spanning portion, or intracellular portion of the receptor. These portions are readily identified by comparison of the amino acid sequence of the receptor with those of known receptors, or by other standard methodology. These fragments are useful for forming chimeric receptors with fragments of other receptors to create a receptor with an intracellular portion which performs a desired function within that cell, and an extracellular portion which causes that cell to respond to the presence of ions, or those agonists or antagonists described herein. Chimeric receptor genes when appropriately formulated are useful in genetic therapies for a variety of diseases involving dysfunction of receptors or where modulation of receptor function provides a desirable effect in the patient.

30 Additionally, chimeric receptors can be constructed such that the intracellular domain is coupled to a desired enzymatic process which can be readily detected by calorimetric, radiometric, luminometric, spectrophotometric or fluorimetric assays and is activated by interaction of the extracellular portion with its native ligand (e.g., calcium) or agonist and/or antagonists of the invention. Cells expressing such chimeric receptors can be used to facilitate screening of inorganic ion receptor agonists and antagonists.

IV. NUCLEIC ACIDS ENCODING ION-RECEPTORS

The invention also features nucleotide sequences encoding inorganic ion receptors and receptor fragments. Nucleotide sequences encoding inorganic ion receptors may be 5 obtained from organisms through a variety of procedures, such as through the use of hybridization probes, antibodies binding a receptor, gene walking, and/or expression assays.

A nucleic acid encoding a particular receptor provides for additional tools to obtain more receptors, for example by providing for hybridization assay probes and antibodies. Furthermore, sequence information from two or more receptors can be analyzed to determine localized sequence conservation which is useful for obtaining still additional clones encoding other members of the superfamily. Conserved sequences also may be derived from an analysis of the overall structure of BoPCaR 1, as it conventionally includes an extracellular domain, transmembrane domain and intracellular domain.

"Conserved nucleic acid regions" refers to two or more nucleic acids encoding an inorganic ion receptor, preferably a calcium receptor, to which a particular nucleic acid sequence can hybridize to under lower stringency conditions. Examples of lower stringency conditions suitable for screening for nucleic acid encoding inorganic ion receptors are provided in the examples below and in Abe et al. J. Biol. Chem., 19:13361 (1992) (hereby incorporated by reference herein). Preferably, conserved regions differ by no more than 7 out of 20 nucleotides.

In preferred embodiments the purified nucleic acid
30 encodes an extracellular domain, but is substantially free of
transmembrane and intracellular domains; the purified nucleic
acid encodes an intracellular domain, but is substantially
free of transmembrane and extracellular domains; the purified
nucleic acid encodes a transmembrane domain, but is

substantially free of an extracellular or intracellular domain; the purified nucleic acid encodes a multiple-transmembrane domain (e.g., a seven-transmembrane domain), but is substantially free of C-terminal intracellular and N-terminal extracellular regions; the purified nucleic acid encodes an extracellular domain which is transcriptionally coupled to nucleic acid encoding a transmembrane, multiple-transmembrane, and/or intracellular domain of a non-inorganic ion receptor or a different inorganic ion receptor and results in a fusion protein; the purified nucleic acid encodes an extracellular domain of a non-inorganic ion receptor or a different inorganic ion receptor which is transcriptionally coupled to nucleic acid encoding a transmembrane, multiple-transmembrane, and/or intracellular domain of an inorganic ion receptor and results in a fusion protein.

In addition, isolated nucleic acid sequences of the invention may be engineered so as to modify processing or expression of receptor sequences. For example, the coding sequence may be combined with an exogenous promoter sequence and/or a ribosome binding site. Another example, is that codons may be modified such that while they encode an identical amino acid, that codon may be a preferred codon in the chosen expression system.

Additionally, a given coding sequence can be mutated *in vitro* or *in vivo*, to create variations in coding regions and/or form new restriction endonuclease sites or destroy preexisting ones, to facilitate further *in vitro* modification. Standard recombinant techniques for mutagenesis such as *in vitro* site-directed mutagenesis (Hutchinson et al., J. Biol. Chem. 253:6551, (1978), Sambrook et al., chapter 15, *supra*), use of TAB® linkers (Pharmacia), and PCR-directed mutagenesis can be used to create such mutations.

Cloning the calcium receptor from different cells will allow the presence of homologous proteins in other cells to be directly assessed. A family of structurally homologous calcium receptor proteins can thus be obtained. Such
5 receptors will allow understanding of how these cells detect extracellular Ca^{2+} and enable evaluation of the mechanism(s) as a site of action for the therapeutics described herein effective in the treatment of for example, HPT, osteoporosis, and hypertension, and novel therapies for other bone and
10 mineral-related diseases.

A. Assays To Detect Receptors

Various assays can be used to detect the presence of an inorganic ion receptor such as calcium receptor and fragments
15 thereof. Such assays include detecting the presence of receptor protein, or receptor activity, expressed by nucleic acid encoding the receptor. Examples of assays for measuring calcium receptor activity are described below. Equivalent assays for other inorganic ion receptors such as Na^+ , K^+ , and
20 phosphate are known in the art.

1. Measurement of Receptor Activity

The ability of nucleic acid to encode a functioning calcium receptor can be conveniently measured using a *Xenopus*
25 expression assay to detect increases in intracellular Ca^{2+} due to receptor activation. Increases in intracellular Ca^{2+} can be measured by different techniques such as by measuring current through the endogenous Ca^{2+} -activated Cl^- channel; loading oocytes with $^{45}\text{Ca}^{2+}$ and measuring mobilization of $^{45}\text{Ca}^{2+}$
30 from intracellular stores; and using fluorescent Ca^{2+} indicators. Expression assays can also be used to measure the calcimimetic and calcilytic activity of agents using *Xenopus* egg containing nucleic acid expressing a functioning calcium receptor.

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Antibodies can be used to screen expression libraries, such as cDNA libraries in λ gt11 to determine the presence of clones expressing antigenically reactive protein. Screening

can be carried out using standard techniques. Sambrook et al., *Molecular Cloning*, chapter 18, Cold Spring Harbor Laboratory Press (1989). Clones testing positive can be purified and then sequenced to determine whether they encode
5 a calcium receptor.

Similarly phage display libraries can be used to clone and analyze calcium receptors in place of monoclonal antibodies. In these libraries, antibody-variable regions or random peptides are shotgun cloned into phage expression
10 vectors such that the antibody regions or peptides are displayed on the surface of the phage particle. Phage(s) which display antibody regions or peptides capable of high specific binding to calcium receptors will bind to cells which display these receptors (e.g., parathyroid cells, C-
15 cells, osteoclasts, etc.). Hundreds of millions of such phage can be panned against these cell types preferentially selecting those phage which can bind to these cells (which includes those phage binding to calcium receptors). In this manner, the complexity of the library can be vastly reduced.
20 Iterative repetition of this process results in a pool of phage which bind to the cell type used. Subsequently, screens for monoclonal antibodies can be used to isolate phage displaying a calcium receptor-binding antibody or peptide regions, and these phage can be used to isolate the
25 calcium receptor for purposes of structural identification and cloning. Kits to prepare such phage-display libraries are commercially available (e.g., Stratacyte, or Cambridge Antibody Technology Limited).

Recombinant phage endowed with such calcium receptor-
30 binding properties can also be used in lieu of monoclonal antibodies in the various analyses of calcium receptors. Such phage can also be used in high-throughput binding-competition screens to identify organic compounds capable of functional binding to calcium receptors which can serve as

structural leads for the development of human therapeutics acting at the calcium receptor.

In another alternative, affinity cross-linking of radioligands to their receptors can be used to isolate the receptor protein as described by Pilch & Czech, 1 Receptor Biochem. Methodol. 161, 1984. Covalent attachment of a radioligand allows extensive washing to remove non-specific binding. For example, a high-affinity molecule, e.g., a random copolymer of arginine and tyrosine (MW = 22K; argtyr ratio = 4:1) which mobilizes intracellular Ca^{2+} with an EC_{50} of about 100 nM or less, is iodinated with ^{125}I , and cross-linked. Protamines, because of their much smaller size, may be preferable in cross-linking studies and can be reductively alkylated as described by Dottavio-Martin & Ravel, 87 Analyt. Biochem. 562, 1978.

Nonspecific labelling is kept to a minimum by cross-linking in the presence of unlabeled polycations and di- and trivalent cations. At high concentrations of these molecules, nonspecific interactions of the label with the cell surface might be reduced.

B. Expression Assay

This section describes techniques to clone bovine and human parathyroid cell calcium receptor cDNAs by functional expression in *Xenopus* oocytes. Adult female *Xenopus laevis* were obtained from *Xenopus* I (Ann Arbor, MI) and maintained according to standard procedures. Lobes of ovary were excised from hypothermically anesthetized toads. Clusters of oocytes were transferred into modified Barth's saline (MBS). Individual oocytes were obtained by incubation in MBS containing 2 mg/ml collagenase (Sigma, Type 1A) for 2 hours at 21°C and stage V-VI oocytes were selected for injection.

Glass capillary tubes (1 mm diameter) were pulled to a fine tip and manually broken to achieve a tip diameter of

about 15 μ meters. A droplet of mRNA (1 ng/nl in diethylpyrocarbonate (DEPC)-treated water) was placed onto PARAFILM™ and drawn into the capillary tube by suction. The capillary tube was then connected to a picospritzer (WPI Instruments) and the volume of the air-pulsed droplets adjusted to deliver 50 ng of mRNA (typically 50 nl). A 35-mm culture dish with a patch of nylon stocking fixed to the bottom was used to secure the oocytes during injection of mRNA into the vegetal pole. The injected oocytes were placed into a 35-mm culture dish containing MBS, 100 μ g/ml penicillin and 100 μ g/ml streptomycin and incubated at 18°C for 3 days.

Following incubation, an oocyte was placed into a 100- μ l plastic chamber and superfused with MBS at a flow rate of 0.5 ml/min using a peristaltic pump. Test molecules or inorganic polycations were added by rapidly moving the tubing into different buffers. Recording and current-passing electrodes were constructed from thin-wall capillary tubing pulled to a resistance of 1-3 Mohms and filled with 3 M KCl. Oocytes were impaled (in the animal pole) with both electrodes under microscopic observation and connected to an Axon Instruments Axoclamp 2A voltage-clamp amplifier which was used to set the holding potential (-70 to -80 mV) and to measure the currents that were passed to maintain the holding potential. Currents were recorded directly onto a strip chart recorder.

For mRNA preparation, tissue was obtained from calves or patients with secondary HPT undergoing surgical removal of the parathyroid glands. Whole pieces of gland were used to prepare mRNA that directs the expression of the calcium receptor in *Xenopus* oocytes. Total cellular RNA was obtained by acid guanidinium thiocyanate/phenol extraction of homogenized glands. Oligo-dT cellulose chromatography was used to select poly(A)⁺-mRNA by standard procedures.

Size fractionation of mRNA was carried out by centrifugation through glycerol gradients. The mRNA was denatured with 20 mM methylmercuric hydroxide and loaded (50-100 μ g at a concentration of 1 mg/ml) onto a linear 15-30% glycerol gradient prepared in Beckman TLS55 tubes. Following centrifugation at 34,000 rpm for 16 hours, 0.3 ml gradient fractions were collected and diluted in an equal volume of water containing 5 mM beta-mercaptoethanol. The mRNA was then recovered by two cycles of ethanol precipitation.

10 The mRNA (50-100 μ g of poly(A)⁺) can also be separated on a 1.2% agarose/6.0 M urea preparative gel, along with a range of RNA size markers. Following visualization of the mRNA by ethidium bromide staining, gel slices containing RNA approximately 1 kb to 2 kb in size are excised. The mRNA is
15 recovered from the agarose gel slices using RNAid binding matrix (according to the supplier's standard protocol; Stratagene, Inc.) and recovered mRNA fractions eluted into DEPC-treated water.

Amounts of recovered mRNA were quantified by UV
20 absorbance measurement. The size range of mRNA contained within each fraction of the glycerol gradient was determined by formaldehyde/agarose gel electrophoresis using a small quantity (0.5 μ g) of each sample.

The integrity of the mRNA was assessed by in vitro
25 translation. Reticulocyte lysates (commercially available kits; BRL) were used to translate 0.05-0.5 μ g of each mRNA fraction. The resulting ³⁵S-labelled proteins were analyzed by SDS-PAGE. Intact mRNA was capable of directing the synthesis of proteins of a complete size range, corresponding
30 roughly to the sizes of the individual mRNA fractions.

A cDNA library was then constructed in the vector λ ZAPII, using a modifications of the techniques described by Gubler and Hoffman. RNA fractions were tested for their ability to induce Cl⁻ current. Fractions giving the best

response in the oocyte assay were used as starting material for cDNA synthesis.

First-strand cDNA synthesis was primed with an oligo-dT/NotI primer-linker. Second-strand synthesis was performed using the RNase H/DNA Polymerase I self-priming method. Double-stranded cDNA was blunted with T4 DNA polymerase and EcoRI adaptors blunt-end ligated to the cDNA with T4 ligase. Following NotI digestion to cleave the linker, full-length cDNA was size-selected by exclusion chromatography on Sephacryl 500 HA. First-strand cDNA was radiolabeled with α -³²P-dATP, and all synthesis and recovery steps monitored by following the incorporation of radioactivity. Full-length cDNA recovered from the sizing column was ligated to EcoRI/NotI digested λ ZAPII arms. The ligation mix was test packaged with commercially available high-efficiency packaging extract (Stratagene, Inc.) and plated on the appropriate host strain (XL1-blue). The percentage of recombinant phage was determined by the ratio of white-to-blue plaques when the library was plated on IPTG and X-gal.

The average insert size was determined from ten randomly selected clones. Phage DNA "mini-preps" were digested with EcoRI and NotI to release the insert, and the size determined by agarose gel electrophoresis. The library consisted of >90% recombinant phage, and the insert size ranged from 1.5 to 4.2 kb. The recombinant ligation was packaged in large scale to generate 800,000 primary clones. The packaging mix was titered and plated at 50,000 plaques per 15 cm plate. Each pool of 50,000 clones was eluted in SM buffer and stored individually.

Plate lysate stocks of each of the clone pools were used for small-scale phage DNA preparation. Phage particles were concentrated by polyethylene glycol precipitation, and phage DNA purified by proteinase K digestion followed by phenol-chloroform extraction. Twenty micrograms of DNA were

digested with NotI, and used as template for *in vitro* transcription of sense-strand RNA. *In vitro* transcription was carried out according to standard protocols, utilizing T7 RNA polymerase and 5' cap analog m⁷GpppG in a 50 μ l total reaction volume. Following Dnase I/Proteinase K digestion and phenol-chloroform extraction, the RNA was concentrated by ethanol precipitation and used for oocyte injection.

Oocytes were injected with synthetic mRNA (cRNA) from each of the 16 library subpools constituting 50,000 independent clones each. After incubation for 3 to 4 days, oocytes were assayed for the ability of 10 mM neomycin to elicit a Ca²⁺-dependent Cl⁻ current. A pool designated "pool 6" gave a positive signal and thus contains a cDNA clone encoding a functional calcium receptor.

Pool 6 phage was replated at about 20,000 plaques per plate and 12 plates harvested. DNA was prepared from each of these subpools and cRNA synthesized. Again, oocytes were injected with cRNA and assayed 3-4 days later for the ability of 10 mM neomycin to elicit a Ca²⁺-dependent Cl⁻ current. A subpool, pool 6-3, was positive and this pool was subjected to a further round of plating, reducing the complexity of pools to around 5,000 clones per pool. Pools were again assayed by preparation of cRNA and injection in oocytes. A subpool, pool 6-3.4, was positive.

To further purify the positive clone in pool 6-3.4, phage DNA from this pool was rescued as plasmid DNA by superinfection with the helper phage, ExAssist (Stratagene). Transfection of rescued plasmids into bacterial strain DH5alphaF' resulted in transformed bacterial colonies on ampicillin plates. These were harvested in pool of 900 clones each. Plasmid DNA was then prepared from each subpool and cRNA synthesized and assayed in the usual manner. Subpool 6-3.4.4 was positive.

Bacteria containing the plasmid subpool 6-3.4.4 were subsequently plated in subpools of about 50 clones each. Continuation of this process is expected to result in a single clone encoding a functional calcium receptor.

5

3. Calcium-Trapping Assay

This section describes a "calcium-trapping assay" for the detection of COS 7 cells expressing G protein-coupled receptors. In this assay COS 7 cell monolayers are transfected with cDNA clones from a bovine parathyroid cDNA library (e.g., subfractions or pools from a library prepared in pCDNA1) and are assayed for their ability to trap radioactive $^{45}\text{Ca}^{2+}$ in response to treatment with an agonist for the calcium receptor. The monolayers undergo emulsion autoradiography and cells that have trapped $^{45}\text{Ca}^{2+}$ are identified by the presence of photographic grain clusters under dark-field microscopy. Library pools that produce a positive signal are then sequentially subdivided until a single cDNA that produces the signal is identified.

20

C. Hybrid-Depletion Assay

A hybrid depletion assay can be used to obtain mRNA encoding inorganic ion receptors. In this approach, clones are selected on the basis of their ability to deplete a specific mRNA species from the total mRNA population. A clone encoding a single subunit is identified by its ability to prevent the formation of the active multi-subunit complex. By exhaustive screening it is possible to identify clones encoding all of the necessary subunits.

Thus, the hybrid-depletion screening strategy can result in the isolation of clones that do not contain a complete protein coding region. Positive clones isolated by this screening strategy are sequenced to determine their protein coding capacity. Northern blot analysis of human parathyroid

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gland RNA permits the determination of the size of the complete mRNA corresponding to specific clones. If positive clones do not appear to be full length, the cloned cDNA will be used as a hybridization probe to screen a parathyroid gland cDNA library for complete cDNAs.

For example, human parathyroid cells express a beta-adrenergic receptor coupled to adenylate cyclase. This receptor can be expressed in oocytes, where it is capable of agonist-induced activation of the endogenous adenylate cyclase. During the hybrid-depletion screening for Ca^{2+} receptor clones, oocytes injected with hybrid-depleted mRNA are assayed for isoproterenol-induced adenylate cyclase activation. A positive response in this assay serves to indicate that any observed inhibition of Ca^{2+} receptor response is specific, and not due to a general inhibition of G protein receptor functions.

D. Cloning Using Hybridization Probes and Primers

The presently preferred method for isolating inorganic ion receptor nucleic acid is based upon hybridization screening. Region-specific primers or probes derived from nucleic acid encoding a calcium receptor can be used to prime DNA synthesis and PCR amplification, as well as to identify colonies containing cloned DNA encoding a member of the inorganic ion receptor family using known methods (e.g., Innis et al., PCR Protocols, Academic Press, San Diego, CA (1990)).

1. PCR Cloning

Primer hybridization specificity to target nucleic acid encoding an inorganic ion receptor can be adjusted by varying the hybridization conditions. When annealing at higher stringency conditions of 50-60°C, sequences which are greater than about 76% homologous to the primer will be amplified.

By employing lower stringency conditions, annealing at 35-37°C, sequences which are greater than about 40-50% homologous to the primer will be amplified.

Analysis of the calcium receptor indicates that it is a G protein-coupled receptor having seven conserved. One particularly useful approach is to employ degenerate primers homologous to the conserved transmembrane domain coding regions and to amplify DNA regions encoding these sequences using polymerase chain reaction (PCR). Thus, such oligonucleotide primers are mixed with genomic DNA or cDNA to RNA isolated from the tissue of choice and PCR carried out. Some experimentation may be required to specifically amplify novel G protein-coupled receptor sequences from the tissue of choice since these are not necessarily identical to already known G protein-coupled receptors, but this is well understood by those of ordinary skill in the art (see, for example, Buck, L. and Axel, R. (1991) Cell, 65:175-187).

2. Hybridization Assay Probes

Hybridization assay probes can be designed based on sequence information obtained from cloned calcium receptors and amino acid sequences encoding such receptors. Hybridization assay probes can be designed to detect the presence of a particular nucleic acid target sequence perfectly complementary to the probe and target sequences of lesser complementarity by varying the hybridization conditions and probe design.

DNA probes targeted to inorganic ion receptors can be designed and used under different hybridization conditions to control the degree of specificity needed for hybridization to a target sequence. Factors affecting probe design, such as length, G and C content, possible self-complementarity, and wash conditions, are known in the art. (See, for example, Sambrook et al., *Molecular Cloning*, Cold Spring Harbor

Laboratory Press (1989).) Sambrook et al., *Molecular Cloning*, also discusses the design and use of degenerative probes based on sequence polypeptide information.

As a general guideline, high stringency conditions
 5 (hybridization at 50-65°C, 5X SSPC, 50% formamide, wash at 50-65°C, 0.5X SSPC) can be used to obtain hybridization between nucleic acid sequences having regions which are greater than about 90% complementary. Low stringency
 10 conditions (hybridization at 35-37°C, 5X SSPC, 40-45% formamide, wash at 42°C SSPC) can be used so that sequences having regions which are greater than 35-45% complementarity will hybridize to the probe.

Any tissue encoding an inorganic ion receptor can be used as a source for genomic DNA. However, with respect to
 15 RNA, the most preferred source is tissues which express elevated levels of the desired inorganic ion receptor family member.

E. Targeting Gene Walking

20 Targeted gene walking (TGW) is a modification of a standard polymerase chain reaction (PCR) that allows amplification of unknown DNA sequences adjacent to short segments of known sequence. Parker et al., Nucl. Acids Res.,
 25 19: 3055 (1991). Unlike conventional PCR techniques that amplify DNA sequences between two known primer sites, TGW can amplify DNA adjacent to one such site. Thus, TGW can serve as a replacement for conventional cloning and library screening methods for isolating sequences upstream or downstream from known sequences. The procedure can be used
 30 to isolate genes from any starting DNA template for which a limited amount of sequence information is known.

For example, first, several standard PCR reactions are run in parallel using one "targeted primer" and different "walking primers." The targeted primer is a sequence-

specific primer exactly complementary to a known sequence on the DNA molecule of interest, and is directed towards unknown adjacent sequences. The walking primers are non-specific sequences not complementary to DNA near the target primer.

- 5 The walking primers can be any oligonucleotides unrelated to the target primer sequence.

In the first series of PCR, products are produced only when a walking primer anneals to a DNA strand contiguous with and complementary to the strand to which the targeted primer
10 has hybridized. The PCR products of interest are preferably within the 5 kilobase size range. Amplification products are produced with as many as 60% mismatched nucleotides within the walking primer relative to DNA template. Perfect base-pairing is required only for the first two 3' nucleotides of
15 the walking primer, but partial homology is tolerated otherwise. Annealing temperature is a key variable in determining the number of PCR products, as identified by agarose gel electrophoresis.

Second, an oligomer extension assay is performed using
20 an "internal detection primer." This primer represents known sequences between the previous two primers, contiguous with the targeted primer. The internal detection primer is kinased with ^{32}P -gamma-ATP, then used in a single PCR cycle with DNA from the first PCR as template. This extension
25 identifies products in the first PCR contiguous with the targeted primer. These new products are identified by agarose gel electrophoresis and autoradiography. Any products that do not hybridize to the internal detection primer represent non-contiguous amplification products
30 produced by any subset of the primers.

Last, bands identified in the oligomer extension assay are excised from the gel, and reamplified by standard PCR using target primer and the walking primer that produced the

band initially. This new PCR band is then sequenced directly to provide previously unknown sequence information.

To extend information in the opposite direction, complements are made of the targeted and internal detection primers, and their order is reversed in the protocol. The pieces of information obtained from going in both directions are combined.

V. Antibodies

10 Inorganic ion receptors, derivatives, and fragments thereof retaining antigenic determinants can be used to generate antibodies recognizing an inorganic ion receptor. Both polyclonal and monoclonal antibodies can be generated. Because derivatives have a different amino acid sequence than
15 the inorganic ion receptor, the derivative may not have all the antigenic determinants of the inorganic ion receptor which it is related to and may have some different antigenic determinants. Preferably, the inorganic ion receptor is a calcium receptor.

20 Antibodies can be produced and used to purify proteins using standard techniques such as those described by Harlow and Lane in *Antibodies, a Laboratory Manual*, Cold Spring Harbor Laboratory, 1988. Sources of immunogens for antibody production include purified inorganic ion receptors, purified
25 inorganic ion receptor fragments, and whole cells expressing an inorganic ion receptor. Preferably, the immunogen is a purified calcium receptor, purified calcium receptor fragment, or whole cells expressing a purified calcium receptor. An example for obtaining antibodies to a calcium
30 receptor from bovine parathyroid is described below.

For example, whole bovine parathyroid gland cells as the immunogen. Purified, dispersed cells are obtained, and live or fixed cell preparations are injected intraperitoneally into the appropriate mouse strain, according to established

procedures. Standard protocols are followed for immunization schedules and for the production of hybridomas. A two-step screening procedure is used to identify hybridomas secreting monoclonal antibodies that recognize the calcium receptor.

5 The initial screen identifies monoclonal antibodies recognizing parathyroid cell surface antigens. Immunohistochemical techniques are then used to screen hybridoma supernatants for the presence of mouse antibodies that bind to the surface of parathyroid cells. The second
10 screen can be performed on fixed sections of parathyroid gland tissue, or on dispersed cells in primary culture.

 This procedure identifies hybridomas producing monoclonal antibodies to a variety of cell-surface determinants, and monoclonals specific for the calcium
15 receptor would be expected to comprise only a small subset of these. To identify monoclonal antibodies that bind to the calcium receptor, hybridoma supernatants that test positive in the initial screen are assayed for their ability to block the response of cultured parathyroid cells to calcium
20 receptor agonists. Some antibodies that bind to the extracellular domain of the receptor are expected to inhibit or activate ligand binding or to otherwise interfere with or affect receptor activation.

 Monoclonal antibodies positive in both screens are
25 characterized through Western blotting, immunoprecipitation and immunohistochemistry. This permits the determination of the size of the antigen that is recognized and its tissue distribution. The appropriate monoclonal antibody is then used for purification of the calcium receptor protein by
30 immunoaffinity chromatography, following standard techniques.

 Polyclonal antibodies recognizing an ion receptor may be obtained by immunizing rabbits or other mammals with isolated ion receptor polypeptides. Polypeptides used for

immunization can comprise the entire receptor polypeptide or fragments thereof.

Ion receptor polypeptides may be isolated from tissues or cells normally expressing the ion receptor of choice, or
5 from cells constructed for the purpose of recombinant expression of such polypeptides.

VI. Highlighted Uses

This section highlights and expands on some of the uses
10 of the ionomimetic and/or ionolytic molecules, receptor polypeptides, nucleic acids encoding receptor polypeptides and antibodies recognizing receptor polypeptides. Additional uses are discussed in other parts of the application and are
15 apparent to one of ordinary skill in the art reading the application.

A. Treatment of Diseases

Diseases or disorders which can be treated by modulating calcium receptor activity are known in the art. For example,
20 diseases or disorders which can be treated by modulating calcium receptor activity can be identified based on the functional responses of cells regulated by calcium receptor activity. Functional responses of cells regulated by calcium receptor are known in the art, including PTH secretion by
25 parathyroid cells, calcitonin secretion by C-cells, and bone resorption by osteoclasts.

Such functional responses are associated with different diseases or disorders. For example, hyperparathyroidism results in elevated levels of PTH in the plasma. Decreasing
30 the plasma levels of PTH offers an effective means of treating hyperparathyroidism. Likewise, increasing plasma levels of calcitonin is associated with an inhibition of bone resorption. Inhibiting bone resorption is an effective treatment for osteoporosis. Thus, modulation of calcium

receptor activity can be used to treat diseases such as hyperparathyroidism, and osteoporosis.

Those compounds modulating inorganic ion receptor activity, preferably calcium receptor activity, can be used to confer beneficial effects to patients suffering from a variety of diseases or disorders. For example, osteoporosis is an age-related disorder characterized by loss of bone mass and increased risk of bone fracture. Compounds can be used to block osteoclastic bone resorption either directly (e.g., an osteoclast ionomimetic compound) or indirectly by increasing endogenous calcitonin levels (e.g., a C-cell calcimimetic). Alternatively, a calcilytic active on the parathyroid cell calcium receptor will increase circulating levels of parathyroid hormone, stimulating bone formation. All three of these approaches will result in beneficial effects to patients suffering from osteoporosis.

In addition, it is known that intermittent low dosing with PTH results in an anabolic effect on bone mass and appropriate bone remodeling. Thus, compounds and dosing regimens evoking transient increases in parathyroid hormone (e.g., intermittent dosing with a parathyroid cell ionolytic) can increase bone mass in patients suffering from osteoporosis.

Additional diseases or disorders can be identified by identifying additional cellular functional responses, associated with a disease or disorder, which are regulated by calcium receptor activity. Diseases or disorder which can be treated by modulating other inorganic ion receptors can be identified in an analogous manner.

Patient treatment can be carried out using different molecules described herein including: (1) inorganic ion receptor-modulating agents, preferably calcium receptor-modulation agents; (2) inorganic ion receptor proteins and fragments thereof, preferably calcium receptor proteins and

fragments thereof; (3) nucleic acids encoding inorganic ion receptor proteins and fragments thereof, preferably calcium receptor proteins and fragments thereof; and (4) antibodies, and fragments thereof targeted to inorganic ion receptor proteins, preferably a calcium receptor.

1. Inorganic Ion Receptor-Modulating Agents

The inorganic ion receptor-modulating agents of the present invention can exert an affect on an inorganic ion receptor causing one or more cellular effects ultimately producing a therapeutic effect. Different types of diseases or disorders can be treated by modulating inorganic ion receptor activity, preferably calcium receptor activity, such as those having one or more of the following: (1) those characterized by abnormal inorganic ion homeostasis, preferably, calcium homeostasis; (2) those characterized by an abnormal amount of an extracellular or intracellular messenger whose production can be affected by inorganic ion receptor activity, preferably calcium receptor activity; and (3) other diseases or disorders in which modulation of inorganic ion receptor activity, preferably calcium receptor activity, will exert a beneficial effect, for example, in diseases or disorders where the production of an intracellular or extracellular messenger stimulated by receptor activity compensates for an abnormal amount of a different messenger.

Calcium receptor-modulating agents of the present invention can exert an effect on calcium receptor causing one or more cellular effects ultimately producing a therapeutic effect. Different diseases can be treated by the present invention by targeting cells having a calcium receptor. For example, primary hyperparathyroidism (HPT) is characterized by hypercalcemia and abnormal elevated levels of circulating PTH. A defect associated with the major type of HPT is a

diminished sensitivity of parathyroid cells to negative feedback regulation by extracellular Ca^{2+} . Thus, in tissue from patients with primary HPT, the "set-point" for extracellular Ca^{2+} is shifted to the right so that higher than normal concentrations of extracellular Ca^{2+} are required to depress PTH secretion. Moreover, in primary HPT, even high concentrations of extracellular Ca^{2+} often depress PTH secretion only partially. In secondary (uremic) HPT, a similar increase in the set-point for extracellular Ca^{2+} is observed even though the degree to which Ca^{2+} suppresses PTH secretion is normal. The changes in PTH secretion are paralleled by changes in $[\text{Ca}^{2+}]_i$; the set-point for extracellular Ca^{2+} -induced increases in $[\text{Ca}^{2+}]_i$ is shifted to the right and the magnitude of such increases is reduced.

Molecules that mimic the action of extracellular Ca^{2+} are beneficial in the long-term management of both primary and secondary HPT. Such molecules provide the added impetus required to suppress PTH secretion which the hypercalcemic condition alone cannot achieve and, thereby, help to relieve the hypercalcemic condition. Molecules with greater efficacy than extracellular Ca^{2+} may overcome the apparent nonsuppressible component of PTH secretion which is particularly troublesome in the major form of primary HPT caused by adenoma of the parathyroid gland. Alternatively or additionally, such molecules can depress synthesis of PTH, as prolonged hypercalcemia has been shown to depress the levels of preproPTH mRNA in bovine and human adenomatous parathyroid tissue. Prolonged hypercalcemia also depresses parathyroid cell proliferation *in vitro*, so calcimimetics can also be effective in limiting the parathyroid cell hyperplasia characteristic of secondary HPT.

Cells other than parathyroid cells can respond directly to physiological changes in the concentration of extracellular Ca^{2+} . For example, calcitonin secretion from

Isolated osteoclasts respond to increases in the concentration of extracellular Ca^{2+} with corresponding increases in $[\text{Ca}^{2+}]_i$ that arise partly from the mobilization of intracellular Ca^{2+} . Increases in $[\text{Ca}^{2+}]_i$ in osteoclasts are associated with the inhibition of bone resorption. Release of alkaline phosphatase from bone-forming osteoblasts is directly stimulated by calcium.

Calcium also promotes the differentiation of intestinal goblet cells, mammary cells, and skin cells; inhibits atrial natriuretic peptide secretion from cardiac atria; reduces cAMP accumulation in platelets; alters gastrin and glucagon secretion; acts on vascular smooth muscle cells to modify cell secretion of vasoactive factors; and affects cells of the central nervous system and peripheral nervous system.

30 Thus, there are sufficient indications to suggest that Ca^{2+} , in addition to its ubiquitous role as an intracellular signal, also functions as an extracellular signal to regulate the responses of certain specialized cells. Molecules of this invention can be used in the treatment of diseases or

disorders associated with disrupted Ca^{2+} responses in these cells.

Specific diseases and disorders which might be treated or prevented, based upon the affected cells, also include those of the central nervous system such as seizures, stroke, head trauma, spinal cord injury, hypoxia-induced nerve cell damage such as in cardiac arrest or neonatal distress, epilepsy, neurodegenerative diseases such as Alzheimer's disease, Huntington's disease and Parkinson's disease, dementia, muscle tension, depression, anxiety, panic disorder, obsessive-compulsive disorder, post-traumatic stress disorder, schizophrenia, neuroleptic malignant syndrome, and Tourette's syndrome; diseases involving excess water reabsorption by the kidney such as syndrome of inappropriate ADH secretion (SIADH), cirrhosis, congestive heart failure, and nephrosis; hypertension; preventing and/or decreasing renal toxicity from cationic antibiotics (e.g., aminoglycoside antibiotics); gut motility disorders such as diarrhea, and spastic colon; GI ulcer diseases; GI diseases with excessive calcium absorption such as sarcoidosis; and autoimmune diseases and organ transplant rejection.

While calcium receptor-modulating agents of the present invention will typically be used in therapy for human patients, they may also be used to treat similar or identical diseases in other warm-blooded animal species such as other primates, farm animals such as swine, cattle, and poultry; and sports animals and pets such as horses, dogs and cats.

B. Toxin Binding Agents

The invention further provides receptor-binding agents including antibodies and/or fragments thereof which can be conjugated to a toxin moiety, or expressed along with a toxin moiety as a recombinant fusion protein. The toxin moiety will bind to and enter a target cell using the interaction of

the binding agent and the corresponding target cell surface receptor. The toxin moiety results in targeted cell death. Thus, cells having calcium receptors characteristic of a disease or disorder, such as cancers, can be targeted by the present invention.

Suitable toxin moieties bound to a binding agent include proteins such as pokeweed anti-viral protein, abrin, diphtheria exotoxin, or Pseudomonas exotoxin; ricin, and a high energy-emitting radionuclide such as cobalt-60. Other examples of possible toxin moieties are known in the art. See, for example, "Conjugate Vaccines", Contributions to Microbiology and Immunology, J.M. Cruse and R.E. Lewis, Jr. (eds.), Carger Press, New York, (1989). The chosen toxin moiety should be pharmaceutically acceptable.

The conjugation of the binding agent to another moiety (e.g., bacterial toxin) can be accomplished by linking the two molecules using standard techniques so long as both molecules retain their respective activity. Possible linkages can be obtained by different chemical mechanisms, for example, covalent binding, affinity binding, intercalation, coordinate binding and complexation. Preferably, covalent binding is used. Covalent binding can be achieved either by direct condensation of existing side chains or by the incorporation of external bridging molecules.

Many bivalent or polyvalent linking agents are useful in coupling protein molecules, such as an antibody, to other molecules. Representative coupling agents include organic compounds such as thioesters, carbodiimides, succinimide esters, diisocyanates, glutaraldehydes, diazobenzenes and hexamethylene diamines. (See Killen and Lindstrom 1984, "Specific killing of lymphocytes that cause experimental autoimmune myasthenia gravis by toxin-acetylcholine receptor conjugates." J. Immunol. 133: 1335-2549; Jansen, F.K., H.E.

Blythman, D. Carriere, P. Casella, O. Gros, P. Gros, J.C. Laurent, F. Paolucci, B. Pau, P. Poncelet, G. Richer, H. Vidal, and G.A. Voisin. 1982. "Immunotoxins: Hybrid molecules combining high specificity and potent cytotoxicity." Immunological Rev. 62: 185-216; and Vitetta et al., *supra*).

B. In Vitro Diagnostics

The different molecules of the present invention can be used to facilitate diagnosis of calcium-related diseases. Diagnosis can be carried *in vitro* or *in vivo*. For example, the molecules of the present invention can be used to assay for defects in calcium receptors and the ability of a cell to properly respond to extracellular calcium. Cells can be obtained from patients using standard medical techniques.

Ionomimetics and ionolytics, such as calcimimetics and calcilytics can be used to assay the responsiveness of a cell or tissue to extracellular calcium. For example, a tissue or a cell type such as an osteoclast can be obtained from a patient and treated with a calcimimetic. The cell's failure to respond to the calcimimetic indicates a defect in calcium receptor activity.

Nucleic acids encoding calcium receptors can be used to help determine whether a particular cellular defect is due to a defective calcium receptor or at a different point in calcium homeostasis. For example, after a cell defective in calcium homeostasis is identified, a nucleic acid encoding a functional calcium receptor can be inserted into the cell. The ability of the calcium receptor to return calcium homeostasis to normal indicates the defect is due to a calcium receptor.

Nucleic acid probes can be used to identify defects in calcium receptors occurring at the genetic level. For example, hybridization probes complementary to nucleic acid

encoding a receptor can be used to clone the receptor. The cloned receptor can be inserted into a cell, such as an oocyte, and its responsiveness to a calcimimetic or calcilytic determined. Another example of using hybridization assay probes to detect defects involves using the probes to detect mRNA levels or the presence of nucleic acid sequences associated with a particular disease. A decreased mRNA level would be consistent with a decreased amount of expressed receptor.

Antibodies and fragments thereof able to recognize a calcium receptor antigen can be used to help determine calcium receptor number, integrity, structure, and to localize cells expressing calcium receptors in the body. For example, antibodies targeted to calcium receptors can be used to determine the number of receptors on a cell; antibodies able to distinguish defective from normal receptors can be used to determine the presence of defective receptors; antibodies targeted to a calcium receptor can be used to determine if a disease or surgical procedure results in the spread of normal or abnormal cells expressing calcium receptors; and antibodies targeted to a calcium receptor can be used to localize cells having abnormal calcium receptor number or structure to direct subsequent treatment.

C. Administration

The different molecules described by the present invention can be used to treat different diseases or disorders by modulating inorganic ion receptor activity, preferably calcium receptor activity. The molecules of the invention can be formulated for a variety of modes of administration, including systemic and topical or localized administration. Techniques and formulations generally may be found in Remington's Pharmaceutical Sciences, Mack Publishing Co., Easton, PA.

Suitable dosage forms, in part, depend upon the use or the route of entry, for example oral, transdermal, or by injection. Such dosage forms should allow the agent to reach a target cell whether the target cell is present in a multicellular host or in culture. For example, pharmacological agents or compositions injected into the blood stream should be soluble. Other factors are known in the art, and include considerations such as toxicity and dosage form which retard the agent or composition from exerting its effect.

Agents can also be formulated as pharmaceutically acceptable salts (e.g., acid addition salts) and complexes thereof. Pharmaceutically acceptable salts are non-toxic salts at the concentration at which they are administered. The preparation of such salts can facilitate the pharmacological use by altering the physical characteristic of the agent without preventing it from exerting its physiological effect. Useful alterations in physical properties include lowering the melting point to facilitate transmucosal administration and increasing the solubility to facilitate administering higher concentrations of the drug.

Pharmaceutically acceptable salts include acid addition salts such as those containing sulfate, hydrochloride, phosphate, sulfamate, acetate, citrate, lactate, tartrate, methanesulfonate, ethanesulfonate, benzenesulfonate, p-toluenesulfonate, cyclohexylsulfamate and quinate. (See e.g., *supra*. PCT/US92/03736.) Pharmaceutically acceptable salts can be obtained from acids such as hydrochloric acid, sulfuric acid, phosphoric acid, sulfamic acid, acetic acid, citric acid, lactic acid, tartaric acid, malonic acid, methanesulfonic acid, ethanesulfonic acid, benzenesulfonic acid, p-toluenesulfonic acid, cyclohexylsulfamic acid, and quinic acid.

Pharmaceutically acceptable salts can be prepared by standard techniques. For example, the free base form of a compound is dissolved in a suitable solvent, such as an aqueous or aqueous-alcohol solution, containing the
5 appropriate acid and then isolated by evaporating the solution. In another example, a salt is prepared by reacting the free base and acid in an organic solvent.

Carriers or excipients can also be used to facilitate administration of the compound. Examples of carriers and
10 excipients include calcium carbonate, calcium phosphate, various sugars such as lactose, glucose, or sucrose, or types of starch, cellulose derivatives, gelatin, vegetable oils, polyethylene glycols and physiologically compatible solvents. The compositions or pharmaceutical composition can be
15 administered by different routes including intravenously, intraperitoneal, subcutaneous, and intramuscular, orally, topically, or transmucosally.

For systemic administration, oral administration is preferred. Alternatively, injection may be used, e.g.,
20 intramuscular, intravenous, intraperitoneal, and subcutaneous. For injection, the molecules of the invention are formulated in liquid solutions, preferably in physiologically compatible buffers such as Hank's solution or Ringer's solution. In addition, the molecules may be
25 formulated in solid form and redissolved or suspended immediately prior to use. Lyophilized forms can also be produced.

Systemic administration can also be by transmucosal or transdermal means, or the molecules can be administered
30 orally. For transmucosal or transdermal administration, penetrants appropriate to the barrier to be permeated are used in the formulation. Such penetrants are generally known in the art, and include, for example, for transmucosal administration, bile salts and fusidic acid derivatives. In

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addition, detergents may be used to facilitate permeation. Transmucosal administration may be through nasal sprays, for example, or using suppositories. For oral administration, the molecules are formulated into conventional oral administration dosage forms such as capsules, tablets, and liquid preparations.

For topical administration, the molecules of the invention are formulated into ointments, salves, gels, or creams, as is generally known in the art.

As shown in the examples provided herein, the amounts of various compounds of this invention to be administered can be determined by standard procedures. Generally, a therapeutically effective amount is between about 1 nmole and 3 μ mole of the molecule, preferably 0.1 nmole and 1 μ mole depending on its EC_{50} or IC_{50} and on the age and size of the patient, and the disease or disorder associated with the patient. Generally, it is an amount between about 0.1 and 50 mg/kg, preferably 0.01 and 20 mg/kg of the animal to be treated.

D. Gene and Oligonucleotide Therapy

Gene and oligonucleotide therapy include the use of nucleic acid encoding a functioning inorganic ion receptor, preferably a calcium receptor, and the use of inhibitory oligonucleotides. Inhibitory oligonucleotides include antisense nucleic acids and ribozymes. Gene and oligonucleotide therapy can be performed *ex vivo* on cells which are then transplanted into a patient, or can be performed by direct administration of the nucleic acid or nucleic acid-protein complex into the patient.

A. Antisense Oligonucleotides and Ribozymes

Antisense oligonucleotides and ribozymes are targeted to nucleic acid encoding an inorganic ion receptor, preferably

a calcium receptor, and inhibit protein expression from the targeted nucleic acid. Numerous mechanisms have been proposed to explain the effects of antisense nucleic acids. For example, see Helene, C. and Toulme, J. *Biochimica et Biophysica Acta* 1049:99 (1990), and Uhlmann, E. and Peyman, A. *Chemical Reviews* 90:543 (1990). Proposed mechanisms include hybridization of an antisense oligonucleotides to nascent mRNA causing premature transcription termination and interfering with mRNA processing by hybridizing to a pre-mRNA intron/exon junction. These and several other proposed mechanisms for inhibiting nucleic acid activity by antisense oligonucleotide are based upon the ability of antisense nucleic acid to hybridize to a target nucleic acid sequence. Preferably, anti-sense nucleic acids are 15 to 30 bases in length.

Ribozymes are enzymatic RNA molecules capable of catalyzing the specific cleavage of RNA. Ribozyme action involves sequence specific interaction of the ribozyme to complementary target RNA, followed by a endonucleolytic cleavage. Different ribozyme cutting motifs such as hammer-head can be engineered to specifically and efficiently catalyze endonucleolytic cleavage of specific RNA sequences encoding.

Specific ribozyme cleavage sites include GUA, GUU and GUC. Once cleavage sites are identified, short RNA sequences of between 15 and 20 ribonucleotides targeted to the region of the targeted RNA containing the cleavage site may be evaluated for predicted structural features to determine ribozyme suitability. The suitability of candidate targets may also be evaluated by testing their accessibility to hybridization with complementary oligonucleotides, using ribonuclease protection assays. See, Draper PCT WO 93/23569, hereby incorporated by reference herein.

Anti-sense oligonucleotides and ribozymes may be prepared by methods known in the art for the synthesis of RNA and DNA molecules. Standard techniques for chemically synthesizing nucleic acids include solid phase phosphoramidite chemical synthesis. Specific nucleic acids can also be produced enzymatically using a host transformed with a plasmid encoding for the desired nucleic acid.

Various modifications to the nucleic acid may be introduced to increase intracellular stability and half-life. Possible modifications include modifications to the phosphodiester backbone such as the use of phosphorothioate or methylphosphonate linkages.

Antisense oligonucleotides and ribozymes can be administered to a patient using different techniques such as by naked nucleic acid, nucleic acid compositions (for example, encapsulated by a liposome) and by retroviral vectors. Miller, Nature 357; 455-460, hereby incorporated by reference herein. Antisense oligonucleotide and ribozymes can also be introduced into a cell using nucleic acid encoding the antisense nucleic acid or ribozyme.

B. Gene Therapy

Gene therapy can be achieved by transferring a gene encoding an inorganic ion receptor, preferably a calcium receptor, into a patient in a manner allowing expression of the receptor protein. Recombinant nucleic acid molecules encoding receptor protein sequences can be introduced into a cell *in vivo* or *ex vivo*. *In vivo* transfection techniques include the use of liposomes and retroviral vectors. Miller, Nature 357; 455-460, hereby incorporated by reference herein. *Ex vivo* transfection increases the number of available transfection techniques, but also adds additional complications due to removal and subsequent insertion of cells into a patient.

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E. Transgenic Animals

The present invention also concerns the construction and use of transgenic animals, and transformed cells encoding inorganic ion receptors, preferably human calcium receptors.

5 Transgenic animals and transformed cells can be used to study the effects on cell function of receptor excess or depletion. Experimental model systems may be used to study the effects in cell or tissue cultures, in whole animals, or in particular cells or tissues within whole animals or tissue
10 culture systems. The effects can be studied over specified time intervals (including during embryogenesis).

The present invention provides for experimental model systems for studying the physiological role of the receptors. Model systems can be created having varying degrees of receptor expression. For example, the nucleic acid encoding a receptor may be inserted into cells which naturally express the receptors such that the gene is expressed at much higher levels. Alternatively, a recombinant gene may be used to inactivate the endogenous gene by homologous recombination, and thereby create an inorganic ion receptor deficient cell, tissue, or animal.

Inactivation of a gene can be caused, for example, by using a recombinant gene engineered to contain an insertional mutation (e.g., the neo gene). The recombinant gene is inserted into the genome of a recipient cell, tissue or animal, and inactivates transcription of the receptor. Such a construct may be introduced into a cell, such as an embryonic stem cell, by techniques such as transfection, transduction, and injection. Stem cells lacking an intact receptor sequence may generate transgenic animals deficient in the receptor.

Preferred test models are transgenic animals. A transgenic animal has cells containing DNA which has been artificially inserted into a cell and inserted into the

genome of the animal which develops from that cell. Preferred transgenic animals are primates, mice, rats, cows, pigs, horses, goats, sheep, dogs and cats.

A variety of methods are available for producing
5 transgenic animals. For example, DNA can be injected into the pronucleus of a fertilized egg before fusion of the male and female pronuclei, or injected into the nucleus of an embryonic cell (e.g., the nucleus of a two-cell embryo) following the initiation of cell division (Brinster et al.,
10 Proc. Nat. Acad. Sci. USA 82: 4438-4442 (1985)). By way of another example, embryos can be infected with viruses, especially retroviruses, modified to carry inorganic ion receptor nucleotide sequences.

Pluripotent stem cells derived from the inner cell mass
15 of the embryo and stabilized in culture can be manipulated in culture to incorporate nucleotide sequences of the invention. A transgenic animal can be produced from such stem cells through implantation into a blastocyst that is implanted into a foster mother and allowed to come to term. Animals
20 suitable for transgenic experiments can be obtained from standard commercial sources such as Charles River (Wilmington, MA), Taconic (Germantown, NY), and Harlan Sprague Dawley (Indianapolis, IN).

Methods for the culturing of embryonic stem (ES) cells
25 and the subsequent production of transgenic animals by the introduction of DNA into ES cells using methods such as electroporation, calcium phosphate/DNA precipitation and direct injection also are well known to those of ordinary skill in the art. See, for example, Teratocarcinomas and
30 Embryonic Stem Cells, A Practical Approach, E.J. Robertson, ed., IRL Press (1987).

Procedures for embryo manipulations are well known in the art. The procedures for manipulation of the rodent embryo and for microinjection of DNA into the pronucleus of

the zygote are well known to those of ordinary skill in the art (Hogan et al., supra). Microinjection procedures for fish, amphibian eggs and birds are detailed in Houdebine and Chourrout, Experientia 47: 897-905 (1991). Other procedures
5 for introduction of DNA into tissues of animals are described in U.S. Patent No. 4,945,050 (Sandford et al., July 30, 1990).

Transfection and isolation of desired clones can be carried out using standard techniques (e.g., E.J. Robertson,
10 supra). For example, random gene integration can be carried out by co-transfecting the nucleic acid with a gene encoding antibiotic resistance. Alternatively, for example, the gene encoding antibiotic resistance is physically linked to a nucleic acid sequence encoding an inorganic ion receptor.

15 DNA molecules introduced into ES cells can also be integrated into the chromosome through the process of homologous recombination. Capecchi, Science 244: 1288-1292 (1989). Methods for positive selection of the recombination event (e.g., neomycin resistance) and dual positive-negative
20 selection (e.g., neomycin resistance and gancyclovir resistance) and the subsequent identification of the desired clones by PCR have been described by Capecchi, supra and Joyner et al., Nature 338:153-156 (1989), the teachings of which are incorporated herein.

25 The final phase of the procedure is to inject targeted ES cells into blastocysts and to transfer the blastocysts into pseudopregnant females. The resulting chimeric animals are bred and the offspring are analyzed by Southern blotting to identify individuals that carry the transgene.

30 An example describing the preparation of a transgenic mouse is as follows. Female mice are induced to superovulate and placed with males. The mated females are sacrificed by CO₂ asphyxiation or cervical dislocation and embryos are recovered from excised oviducts. Surrounding cumulus cells

are removed. Pronuclear embryos are then washed and stored until the time of injection.

Randomly cycling adult female mice paired with vasectomized males serve as recipients for implanted embryos.

- 5 Recipient females are mated at the same time as donor females and embryos are transferred surgically to recipient females.

The procedure for generating transgenic rats is similar to that of mice. See Hammer et al., Cell 63:1099-1112 (1990). Procedures for the production of transgenic non-rodent mammals and other animals are known in art. See, for example, Houdebine and Chourrout, *supra*; Pursel et al., Science 244:1281-1288 (1989); and Simms et al., Bio/Technology 6:179-183 (1988).

15 F. Transfected Cells Lines

Nucleic acid expressing a functional inorganic ion receptor can be used to create transfected cells lines which functionally express a specific inorganic ion receptor. Such cell lines have a variety of uses such as being used for high-throughput screening for molecules able to modulate inorganic ion receptor activity, preferably calcium receptor activity; and being used to assay binding to an inorganic ion receptor, preferably a calcium receptor.

A variety of cell lines are capable of coupling exogenously expressed receptors to endogenous functional responses. A number of these cell lines (e.g., NIH-3T3, HeLa, NG115, CHO, HEK 293 and COS7) can be tested to confirm that they lack an endogenous calcium receptor. Those lines lacking a response to external Ca^{2+} can be used to establish stably transfected cell lines expressing the cloned calcium receptor.

Production of these stable transfectants is accomplished by transfection of an appropriate cell line with a eukaryotic expression vector, such as pMSG, in which the coding sequence

for the calcium receptor cDNA has been cloned into the multiple cloning site. These expression vectors contain a promoter region, such as the mouse mammary tumor virus promoter (MMTV), that drive high-level transcription of cDNAs in a variety of mammalian cells. In addition, these vectors contain genes for the selection of cells that stably express the cDNA of interest. The selectable marker in the pMSG vector encodes an enzyme, xanthine-guanine phosphoribosyl transferase (XGPRT), that confers resistance to a metabolic inhibitor that is added to the culture to kill the nontransfected cells. A variety of expression vectors and selection schemes are usually assessed to determine the optimal conditions for the production of calcium receptor-expressing cell lines for use in high-throughput screening assays.

The most effective method for transfection of eukaryotic cell lines with plasmid DNA varies with the given cell type. The calcium receptor expression construct will be introduced into cultured cells by the appropriate technique, either Ca^{2+} phosphate precipitation, DEAE-dextran transfection, lipofection or electroporation.

Cells that have stably incorporated the transfected DNA will be identified by their resistance to selection media, as described above, and clonal cell lines will be produced by expansion of resistant colonies. The expression of the calcium receptor cDNA by these cell lines will be assessed by solution hybridization and Northern blot analysis. Functional expression of the receptor protein will be determined by measuring the mobilization of intracellular Ca^{2+} in response to externally applied calcium receptor agonists.

The following examples illustrate the invention, but do not limit its scope.

EXAMPLES

In the studies described herein, a variety of organic molecules were found to mobilize intracellular Ca^{2+} and depress PTH secretion in parathyroid cells. These molecules are structurally diverse, but most have a net positive charge at physiological pH. The cationic nature of the organic molecules plays an important role, but is not the sole factor determining activity.

10 Example 1: Screening Calcimimetic Molecules on Bovine Parathyroid cells

Dissociated bovine parathyroid cells were purified on gradients of Percoll and cultured overnight in serum-free medium. The cells were subsequently loaded with fura-2 and the concentration of free intracellular Ca^{2+} measured fluorimetrically. Changes in $[\text{Ca}^{2+}]_i$ were used to screen for molecules active at the calcium receptor. To be considered a calcimimetic in this example, a molecule was required to show the normal effects caused by increasing extracellular Ca^{2+} and triggered by the activation of the calcium receptor. That is,

1) The molecule must elicit an increase in $[\text{Ca}^{2+}]_i$; the increase in $[\text{Ca}^{2+}]_i$ may persist in the absence of extracellular Ca^{2+} and/or the molecule may potentiate increases in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} .

2) The molecule must cause a decrease in isoproterenol-stimulated cyclic AMP formation which is blocked by pertussis toxin;

3) The molecule must inhibit PTH secretion over the same range of concentrations that cause the increase in $[\text{Ca}^{2+}]_i$; and

4) The concentration-response curves for increases in $[\text{Ca}^{2+}]_i$ and PTH secretion by the molecule must be shifted to

the right by a PKC activator, such as phorbol myristate acetate (PMA).

Several structurally different classes of molecules were tested: polyamines, aminoglycoside antibiotics, protamine, and polymers of lysine or arginine. The structures of these molecules are depicted in Figure 1. Included in Figure 1 are the net positive charge of the molecules and their EC_{50} 's for evoking the mobilization of intracellular Ca^{2+} in bovine parathyroid cells.

In general, the greater the net positive charge on the molecule, the greater its potency in causing the mobilization of intracellular Ca^{2+} . However, some striking exceptions to this apparent general rule have been found as discussed below.

As can be seen from the figures, spermine, neomycin B, and protamine evoked rapid and transient increases in $[Ca^{2+}]_i$ in fura-2-loaded bovine parathyroid cells (Figs. 6, 7, 11). They did not, however, cause sustained, steady-state increases in $[Ca^{2+}]_i$ in bovine parathyroid cells (Fig. 6, 11), although they did in human parathyroid cells (Fig. 19). In this respect, they resembled the cytosolic Ca^{2+} response elicited by extracellular Mg^{2+} , which causes the mobilization of intracellular Ca^{2+} unaccompanied by an influx of extracellular Ca^{2+} in bovine cells (Fig. 11b). Transient increases in $[Ca^{2+}]_i$ elicited by spermine, neomycin B, or protamine were not blocked by low concentrations ($1 \mu M$) of La^{3+} or Gd^{3+} (Fig. 11f,g). Cytosolic Ca^{2+} transients elicited by the molecular polycations persisted in the absence of extracellular Ca^{2+} , but were blocked when cellular stores of Ca^{2+} were depleted by pretreatment with ionomycin (Figs. 7, 11h and 11i.). All of these molecules therefore cause the mobilization of intracellular Ca^{2+} in parathyroid cells.

It was additionally shown that the molecular polycations mobilized the same pool of intracellular Ca^{2+} as that used by

extracellular Ca^{2+} . Thus, increasing the concentration of extracellular Ca^{2+} progressively inhibited the transient increases in $[\text{Ca}^{2+}]_i$ evoked by spermine (Fig. 6). Conversely, a maximally effective concentration of spermine or neomycin B (Fig. 12) blocked transient, but not steady-state increases in $[\text{Ca}^{2+}]_i$ evoked by extracellular Ca^{2+} .

Significantly, spermine, neomycin B, and protamine inhibited PTH secretion to the same extent as extracellular Ca^{2+} . These inhibitory effects on secretion were obtained at concentrations that caused the mobilization of intracellular Ca^{2+} (Figs. 8, 13). These findings are relevant to understanding the mechanisms contributing to the regulation of PTH secretion by extracellular Ca^{2+} . Because a variety of inorganic polycations all inhibit secretion, yet only extracellular Ca^{2+} causes sustained, steady-state increases in $[\text{Ca}^{2+}]_i$, such increases in $[\text{Ca}^{2+}]_i$ cannot be importantly involved in the regulation of secretion. Mobilization of intracellular Ca^{2+} , rather than the influx of extracellular Ca^{2+} , is the essential mechanism associated with the inhibition of PTH secretion. This is important because it defines the sufficient mechanism to be affected if a molecule is to affect PTH secretion; molecules stimulating selectively the influx of extracellular Ca^{2+} will be relatively ineffective in suppressing PTH secretion. In contrast, molecules causing solely the mobilization of intracellular Ca^{2+} should be just as efficacious as extracellular Ca^{2+} in suppressing PTH secretion.

Like the mobilization of intracellular Ca^{2+} elicited by extracellular Ca^{2+} , that elicited by molecular polycations was depressed by PMA. A representative experiment showing the preferential inhibitory effects of PMA on cytosolic Ca^{2+} transients elicited by spermine is shown in Fig. 14. Cytosolic Ca^{2+} transients evoked by ATP were unaffected, even when a submaximal concentration of ATP was used. The effect

of PMA on cytosolic Ca^{2+} transients elicited by the molecular polycations paralleled its effect on responses to extracellular Ca^{2+} ; in both cases, there was a shift to the right in the concentration-response curve (Fig. 15). The depressive effects of PMA on $[\text{Ca}^{2+}]_i$ were accompanied by potentiating effects on secretion which were overcome at higher concentrations of the organic polycations (Fig. 16).

The mobilization of intracellular Ca^{2+} elicited by molecular polycations was associated with increases in the formation of inositol phosphates. For example, protamine caused a rapid (within 30 seconds) increase in the formation of IP_3 which was accompanied by a rise in levels of IP_1 . Both these effects were dependent on the concentration of extracellular protamine (Fig. 17). Moreover, pretreatment with PMA blunted the formation of inositol phosphates elicited by molecular polycations. Representative results obtained with spermine are presented in Fig. 18.

Spermine, neomycin B, and protamine depressed isoproterenol-induced increases in cyclic AMP. Like the inhibitory effects of extracellular Ca^{2+} on cyclic AMP formation, those caused by molecular polycations were blocked by pretreatment with pertussis toxin (Table 2).

Table 2

	cyclic AMP (% of control)	
	control	+PTx
0.5 mM Ca^{2+}	100	106 ± 8
2.0 mM Ca^{2+}	19 ± 4	94 ± 2
0.5 mM Ca^{2+} , 200 μM spermine	23 ± 5	93 ± 6
0.5 mM Ca^{2+} , 30 μM neomycin B	28 ± 8	87 ± 6
0.5 mM Ca^{2+} , 2 $\mu\text{g/ml}$ protamine	20 ± 4	89 ± 9

Pertussis toxin (PTx) blocks the inhibitory effects of extracellular Ca^{2+} and molecular polycations on cyclic AMP formation. Bovine parathyroid cells were cultured for 16 hours with or without 100 ng/ml pertussis toxin. The cells
 5 were subsequently washed and incubated for 15 min with 10 μM isoproterenol with or without the indicated concentrations of extracellular Ca^{2+} or molecular polycations. Total cyclic AMP (cells + supernatant) was determined by RIA and the results are expressed as a percentage of the levels obtained
 10 in 0.5 mM Ca^{2+} (112 ± 17 pmole/ 10^6 cells). Each value is the mean \pm SEM of three experiments.

In human parathyroid cells, extracellular Mg^{2+} elicited a sustained, steady-state increase in $[\text{Ca}^{2+}]_i$ in addition to a rapid transient increase (Fig. 10). As in bovine
 15 parathyroid cells responding to extracellular Ca^{2+} , the steady-state increase in $[\text{Ca}^{2+}]_i$ evoked by Mg^{2+} in human parathyroid cells results from Ca^{2+} influx through voltage-insensitive channels (Fig. 10a). This effect of Mg^{2+} on steady-state $[\text{Ca}^{2+}]_i$ in human parathyroid cells is seen in
 20 both adenomatous and hyperplastic tissue.

Neomycin B and spermine were tested for effects on $[\text{Ca}^{2+}]_i$ in human parathyroid cells prepared from adenomatous tissue. Representative results with neomycin B are shown in Fig. 19. Neomycin B caused not only a transient, but
 25 additionally a steady-state increase in $[\text{Ca}^{2+}]_i$ in human parathyroid cells (Fig. 19a). Thus, in human cells, the pattern of change in $[\text{Ca}^{2+}]_i$ evoked by extracellular Ca^{2+} , Mg^{2+} or neomycin B is very similar.

Cytosolic Ca^{2+} transients elicited by neomycin B
 30 persisted in the presence of La^{3+} ($1\mu\text{M}$) and absence of extracellular Ca^{2+} . Neomycin B therefore causes the mobilization of intracellular Ca^{2+} in human parathyroid cells. Neomycin B inhibited PTH secretion from human parathyroid cells at concentrations that caused the

mobilization of intracellular Ca^{2+} (Fig. 13). There were, however, some differences in the responses of human and bovine parathyroid cells to neomycin B. The EC_{50} of neomycin B for the mobilization of intracellular Ca^{2+} was 40 μM in 5 bovine and 20 μM in human parathyroid cells (cf. Figs. 13 and 15), whereas the potency of spermine was similar in bovine and human parathyroid cells ($\text{EC}_{50} = 150 \mu\text{M}$). Thus, although bovine cells can be used for initial studies to screen test molecules for activity, it is important to perform follow-up 10 studies using human parathyroid cells.

To assess the effects of molecular polycations on C-cells, a neoplastic cell line, derived from a rat medullary thyroid carcinoma (rMTC 6-23 cells) was used. Both spermine (10 mM) and neomycin B (5 mM) were without effect on basal 15 $[\text{Ca}^{2+}]_i$ in these cells. Nor did either molecule affect the response to the subsequent addition of extracellular Ca^{2+} . Representative results documenting the lack of effect of neomycin B are shown in Fig. 21. Neomycin B (1 mM) or spermine (1 or 5 mM) failed to evoke any increase in $[\text{Ca}^{2+}]_i$ 20 in osteoclasts (Fig. 23). In the trace shown, there appeared to be some potentiation of the response to a subsequent increase in the concentration of extracellular Ca^{2+} , although this was not a consistent finding. In two other cells, spermine (5 mM) was again without effect on basal $[\text{Ca}^{2+}]_i$ and 25 caused a small inhibition (about 15%) of the extracellular Ca^{2+} -induced increase in $[\text{Ca}^{2+}]_i$. In a third cell, neomycin B (5 mM) was without effect on basal $[\text{Ca}^{2+}]_i$ and did not affect increases in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} . The overall picture that develops from these studies is that 30 spermine and neomycin B are without effect on basal or stimulated levels of cytosolic Ca^{2+} in osteoclasts.

The failure of the molecular polycations to affect the Ca^{2+} -sensing mechanisms of C-cells or osteoclasts demonstrates the ability to discover or design novel lead

molecules that act specifically on the parathyroid cell calcium receptor or otherwise modulate one or more functions of the parathyroid cell's normal response to $[Ca^{2+}]_i$.

Screening of various other molecules is described in detail below and the results summarized in Table 1.

Example 2: Polyamine Screening

Straight-chain polyamines (spermine, spermidine, TETA, TEPA, and PEHA) and two derivatives thereof (NPS 381 and NPS 382) were screened as in Example 1. These molecules were all found to mobilize intracellular Ca^{2+} in bovine parathyroid cells. Their order of potency is as follows, with the net positive charge listed in parentheses:

15	<u>Table 3</u>	
	<u>Molecule</u>	<u>EC₅₀ (in μM)</u>
	NPS 382 (+8)	50
	NPS 381 (+10)	100
	spermine (+4)	150
20	PEHA (+6)	500
	spermidine (+3)	2000
	TEPA (+5)	2500
	TETA (+4)	8000

Putrescine (+2) and cadaverine (+2) were inactive at a concentration of 2 mM.

Another straight-chain polyamine, DADD, behaved somewhat differently from the other polyamines and is described in Example 7.

30

Example 3: Cyclic Polyamine Screening

Two cyclic polyamines, hexacyclen and NPS 383, were screened as in Example 1. Hexacyclen (+6, $EC_{50} = 20 \mu M$) is 7-fold more potent than NPS 383 (+8, $EC_{50} = 150 \mu M$). The converse would be expected based solely on net positive charge as the structural characteristic for calcium receptor activity.

Example 4: Aminoglycoside Antibiotic Screening

Six antibiotics were screened as in Example 1. The resulting EC_{50} 's for the mobilization of intracellular Ca^{2+} , in rank order of potency, were:

Table 4

	<u>Antibiotic</u>	<u>EC_{50} (in μM)</u>
15	neomycin (+6)	10
	gentamicin (+5)	150
	bekanamycin (+5)	200
	streptomycin (+3)	600

Kanamycin (+4.5) and lincomycin (+1) were without effect at a concentration of $500 \mu M$. Within the aminoglycoside series, there is a correlation between net positive charge and potency. However, neomycin is considerably more potent than various polyamines (NPS 381, NPS 382, NPS 383, PEHA) that have an equal or greater positive charge. Since aminoglycoside antibiotics of this type have renal toxicity which may be related to interaction with calcium receptors in the kidney, such screening could be used to screen for toxicity in the development of new aminoglycoside antibiotics.

Example 5: Peptide and Polyamino Acid Screening

Protamine and polymers of lysine or arginine varying in peptide length were screened for their ability to mobilize intracellular Ca^{2+} as in Example 1. The resulting EC_{50} 's for the mobilization of intracellular Ca^{2+} , in rank order of potency, were:

Table 5

	<u>Peptide (MW in kD)</u>	<u>EC_{50} (in nM)</u>
10	polyArg (100)	4
	polyArg (40)	15
	polyLys (27)	30
	protamine (4.8)	75
	polyArgTyr (22)	200
15	polyLys (14)	1000
	polyLys (3.8)	3000

The net positive charge of these polymers increases as the MW increases. Thus, as for the aminoglycosides, there is a direct correlation between net charge and potency among this series of polyamino acids. Protamine is essentially polyArg with a net positive charge of +21.

Example 6: Arylalkyl Polyamine Screening

Molecules selected from the class of arylalkyl polyamines derived from the venoms of wasps and spiders were screened as in Example 1.

Philanthotoxin-433 (+3) was without effect at a concentration of 500 μM . It is similar in structure to the argiotoxins described below.

Argiotoxin-636 (400 μM) did not elicit increases in $[\text{Ca}^{2+}]$, but it did potentiate cytosolic Ca^{2+} responses to the subsequent addition of extracellular Ca^{2+} . This is a feature common to all molecules that activate the calcium receptor

and is also seen with a variety of extracellular divalent cations. This is considered in more detail in Example 7.

In contrast to argiotoxin-636, argiotoxin-659 elicited increases in $[Ca^{2+}]_i$ with an EC_{50} of 300 μM . Argiotoxin-659
5 differs from argiotoxin-636 in having a 4-hydroxyindole moiety rather than a 2,4-dihydroxyphenyl group. This is the only structural difference between these two molecules. Thus, the difference in potency lies in the nature of the aromatic group, not in the polyamine chain which carries the
10 positive charge.

Example 7: Screening of Ca^{2+} Channel Blockers

Ca^{2+} channel blockers, i.e., those molecules which block influx of extracellular Ca^{2+} through voltage-sensitive Ca^{2+}
15 channels, were screened as in Example 1. There are three structural classes of Ca^{2+} channel blockers: (1) dihydropyridines, (2) phenylalkylamines, and (3) benzothiazipines.

None of the dihydropyridines tested (nifedipine, nitrendipine, BAY K 8644, and (-) 202-791 and (+) 202-791)
20 had any effect on basal $[Ca^{2+}]_i$ or increases in $[Ca^{2+}]_i$ evoked by extracellular Ca^{2+} when they were tested at 1 μM . Previous studies showed that parathyroid cells lack voltage-sensitive Ca^{2+} channels, but do have voltage-insensitive Ca^{2+}
25 channels that are regulated by the calcium receptor.

The phenylalkylamines examined were verapamil, D-600 (a methoxy derivative of verapamil), TMB-8, and an analog of TMB-8, NPS 384. The first three molecules were tested at a concentration of 100 μM . The phenylalkylamines behaved
30 differently from other molecules examined. They evoked no change in $[Ca^{2+}]_i$ when added to cells bathed in buffer containing a low concentration of extracellular Ca^{2+} (0.5 mM). However, verapamil, D-600, and TMB-8 potentiated the mobilization of intracellular Ca^{2+} elicited by extracellular

divalent cations and they additionally blocked the influx of extracellular Ca^{2+} . At intermediate levels of extracellular Ca^{2+} (1-1.5 mM), these molecules were capable of evoking a small, but robust increase in $[\text{Ca}^{2+}]_i$ that arose from the mobilization of intracellular Ca^{2+} .

The phenylalkylamines act differently than organic polycations like neomycin. The data suggest that verapamil, D-600 and TMB-8 are partial agonists or allosteric activators at the calcium receptor, in contrast to the other molecules examined which are full agonists.

Molecule NPS 384, at a concentration of 300 μM , did not evoke an increase in $[\text{Ca}^{2+}]_i$, but it blocked influx of extracellular Ca^{2+} . Testing at higher concentrations may reveal an ability of this molecule to cause the mobilization of intracellular Ca^{2+} .

While the ability of these molecules to block influx is intriguing and not entirely unexpected, it is the ability of these molecules to evoke transient increases in $[\text{Ca}^{2+}]_i$ (arising from intracellular Ca^{2+} mobilization) that is important. Considerable experience with measurements of $[\text{Ca}^{2+}]_i$ in parathyroid cells shows that transient increases in $[\text{Ca}^{2+}]_i$ almost invariably result from the mobilization of intracellular Ca^{2+} and therefore reflects activation of the calcium receptor.

The benzothiazepine examined, diltiazem, was similar in all respects to verapamil and D-600 and was also effective at 100 μM .

With the exception of the phenylalkylamines, all the active molecules tested above evoke increases in $[\text{Ca}^{2+}]_i$ having a magnitude similar to that evoked by a maximally effective concentration of extracellular Ca^{2+} . This shows that these molecules are equally efficacious as extracellular divalent cations. This contrasts with the activity of

phenylalkylamines, which seem to act only as partial agonists.

Amongst the phenylalkylamines, some interesting structure-activity relationships emerge. Significant is the
5 different potencies of molecules like TMB-8 and NPS 384. TMB-8 potentiated transient increases in $[Ca^{2+}]_i$ at 100 μM whereas NPS 384 fails to do so even at 300 μM , yet these molecules carry the same net positive charge. It follows that some other structural feature, unrelated to net charge,
10 imparts greater potency to TMB-8.

Example 8: Molecule Screening on Human Parathyroid Cells

Spermine and neomycin were tested for effects on $[Ca^{2+}]_i$ in human parathyroid cells obtained from glands removed by
15 surgery and prepared as in Example 1. In human parathyroid cells, spermine was found to cause only a small increase in $[Ca^{2+}]_i$ when tested at a concentration of 300 μM .

Neomycin, on the other hand, evoked a large increase in $[Ca^{2+}]_i$ in human parathyroid cells when tested at a
20 concentration of 20 μM . The magnitude of the response elicited by neomycin was equal to that evoked by a maximally effective concentration of extracellular Ca^{2+} .

Example 9: Molecule Screening on *Xenopus* Oocytes

Oocytes injected with mRNA from human parathyroid cells
25 express the calcium receptor and mobilize intracellular Ca^{2+} in response to a variety of extracellular inorganic di- and trivalent cations. Using this screen allows one to test for an action directly on the calcium receptor. Oocytes
30 expressing the calcium receptor also responded to several molecules active on intact parathyroid cells when screened as follows. Hexacyclen caused the mobilization of intracellular Ca^{2+} at a concentration of 135 μM . Neomycin (100 μM) and NPS 382 (5 mM) were also effective. This offers rather

compelling evidence showing that these molecules act on the calcium receptor or on some other protein intimately associated with its function.

For example, we have been able to detect calcium
 5 receptor expression in oocytes by measuring $^{45}\text{Ca}^{2+}$
 mobilization. In these experiments, oocytes were injected
 with bovine parathyroid mRNA or water and, after 72 hours,
 exposed to serum or 10 mM neomycin. Prior to being
 stimulated, oocytes were loaded with $^{45}\text{Ca}^{2+}$. Stimulation with
 10 serum for 20 min resulted in intracellular $^{45}\text{Ca}^{2+}$ release
 representing a 45% increase compared to mock challenge with
 buffer. Challenge with 10 mM neomycin for 20 min resulted in
 a 76% increase in $^{45}\text{Ca}^{2+}$ release. The assay is sensitive
 enough for use in cloning the calcium receptor, and has the
 15 advantage of a higher throughput than the
 electrophysiological measurement of Ca^{2+} -activated Cl^-
 current.

In another example, human osteoclastoma tissue was
 obtained from bone biopsy tissue. Oocytes injected with mRNA
 20 isolated from this tissue were challenged with 30 mM Ca^{2+} .
 Controls did not respond while 8 of 12 oocytes injected with
 osteoclastoma mRNA responded appropriately (Fig. 34). These
 experiments provide the first evidence that the Ca^{2+} response
 of osteoclasts to extracellular Ca^{2+} is in fact genetically
 25 encoded. The results also indicate that the osteoclast
 calcium receptor may be cloned by expression in *Xenopus*
 oocytes.

Example 10: Molecule Screening on Rat Osteoclasts

30 The different sensitivities of parathyroid cells and rat
 osteoclasts to extracellular Ca^{2+} suggest that their calcium
 receptors are different. While parathyroid cells respond to
 extracellular Ca^{2+} concentrations between 0.5 and 3 mM,
 osteoclasts respond only when the level of extracellular Ca^{2+}

increases beyond 5 mM. This rather high concentration of Ca^{2+} is nonetheless physiological for osteoclasts; as they resorb bone, the local concentration of extracellular Ca^{2+} may reach levels as high as 30 mM.

5 Molecule screening with rat osteoclasts was performed as follows. Osteoclasts were obtained from the long bones of neonatal rats. $[\text{Ca}^{2+}]_i$ was measured in single cells using the fluorimetric indicator indo-1. Spermine, spermidine, neomycin, and verapamil were tested, and none of these caused
10 any large increase in $[\text{Ca}^{2+}]_i$ in osteoclasts (although small responses were detected).

At a concentration of 1 mM, spermidine caused a small increase in $[\text{Ca}^{2+}]_i$ (about 10% of that evoked by a maximal concentration of extracellular Ca^{2+}). Neither neomycin (10
15 mM) nor spermine (10 or 20 mM) caused increases in $[\text{Ca}^{2+}]_i$ in rat osteoclasts. Neomycin (10 mM) did not block the increase in $[\text{Ca}^{2+}]_i$ elicited by the subsequent addition of 25 mM extracellular Ca^{2+} . Pretreatment with spermine (20 mM), however, did depress the response to extracellular Ca^{2+} .
20 Verapamil (100 μM) caused no detectable increase in $[\text{Ca}^{2+}]_i$, but it did block the response to extracellular Ca^{2+} .

Comparisons between osteoclasts and parathyroid cells show that molecules active on the latter are relatively ineffective in osteoclasts. This demonstrates that drugs
25 that target a specific calcium receptor without affecting those receptor types present on other Ca^{2+} -sensing cells are readily developed. Similarly, drugs active at two or more such calcium receptors may also be developed.

30 Screening for Calcimimetic and Calcilytic Activity on the Osteoclast Calcium Receptor

Compounds possessing activity on the osteoclast calcium receptor can be discovered by measuring $[\text{Ca}^{2+}]_i$ in single rat osteoclasts as described above. An improved assay enables

moderate-to-high levels of compound throughput. This new method is based on the use of rabbit osteoclasts which can be obtained in high yield (10^5 per animal) and purity (95% of the cells are osteoclasts). The purity of the rabbit
5 osteoclast preparation allows measurements of $[Ca^{2+}]_i$ to be performed on populations of cells. Because the recorded fluorescence signal is an averaged population response, intercellular variability is minimized and the precision of the assay is greatly increased. This, in turn, enables more
10 compounds to be screened for activity.

Rabbit osteoclasts are prepared from 6-day old bunnies. The animals are sacrificed by decapitation and the long bones removed and placed into osteoclast medium (OC medium: alpha-minimum essential medium containing 5% fetal bovine serum and
15 penicillin/streptomycin). The bones are cut into sections with a scalpel and placed in 2 ml of OC media in a 50-ml conical centrifuge tube. The bone sections are minced with scissors until a fairly homogeneous suspension of bone particles is obtained. The suspension is then diluted with
20 25 ml of OC media and the preparation swirled gently ("vortexed") for 30 seconds. The bone particles are allowed to settle for 2 minutes after which the supernatant is removed and added to a 50-ml centrifuge tube. The bone particles are resuspended in OC media, swirled, sedimented
25 and harvested as just described. The supernatants from the two harvests are combined and centrifuged and the resulting cellular pellet resuspended in Percoll. The suspension is then centrifuged and the white viscous band just below the meniscus is removed and washed with OC media. The Percoll
30 centrifugation step results in a significant improvement in purity and allows osteoclasts to be plated at high densities, suitable for measuring $[Ca^{2+}]_i$ in populations of cells. The cells are plated onto glass cover slips appropriate for measuring $[Ca^{2+}]_i$ according to one of the methods described

below. If necessary, the purity of the preparation can be improved. In this case, the cells are cultured overnight and then rinsed with Ca^{2+} - and Mg^{2+} -free buffer. The cell monolayer is then immersed in Ca^{2+} - and Mg^{2+} -free buffer
5 containing 0.02% EDTA and 0.001% pronase for 5 minutes. This buffer is then removed and replaced with OC media and the cells allowed to recover for 1 to 2 hours before loading the cells with fluorimetric indicator and measuring $[\text{Ca}^{2+}]_i$ as described below.

10 In one embodiment, this technique allows the measurement of $[\text{Ca}^{2+}]_i$ in populations of osteoclasts using fluorescence microscopy. The purified osteoclasts are allowed to attach to 25-mm diameter glass cover slips and then loaded with indo-1. The cover slips are secured into a superfusion
15 chamber and placed onto the stage of a fluorescence microscope. The use of a low-power objective (x4) allows a field containing 10 to 15 osteoclasts to be visualized. In one variation, the fluorescence of each cell in the field can be recorded simultaneously and stored separately for later
20 analysis. Changes in $[\text{Ca}^{2+}]_i$ of each cell can be estimated and the average response of all cells in the field calculated. In another variation, the fluorescence from the entire field of cells can be recorded and processed immediately. In either variation, the final data are in the
25 form of an average response from the cells present in the microscopic field. Because of this, intercellular variability is minimized and precision of the assay greatly increased. This method enables 10-20 compounds per week to be screened for activity on the osteoclast calcium receptor.

30 In a more preferred embodiment, this technique allows the measurement of $[\text{Ca}^{2+}]_i$ in populations of osteoclasts using a conventional fluorimeter. The purified osteoclasts are allowed to attach to rectangular glass cover slips. In one variation, a standard quartz cuvette (1 cm^2) is used and the

glass coverslips are 2 x 1.35 cm. In another variation, a microcuvette is used (0.5 cm²) and the glass coverslips are 1 x 0.75 cm. In either case the cells are loaded with fura-2 or some other suitable fluorimetric indicator for measuring
5 [Ca²⁺]_i. The fluorescence of indicator-loaded cells is recorded as described above for bovine parathyroid cells. This method allows a higher throughput than fluorescence microscopy and enables 20-50 compounds per week to be evaluated for activity on the osteoclast calcium receptor.

10 In a most preferred embodiment, the technique can be used to measure [Ca²⁺]_i in osteoclasts in a 96-well plate. The purified osteoclasts are plated at high density into each well of a 96-well plate and subsequently loaded with a suitable fluorimetric indicator. The fluorescence of each
15 well is recorded using a custom-designed fluorimeter attached to a Hamilton 220 robotic liquid handler. This method is the fully automated and is capable of reading 1,000 compound per week per device.

20 Example 11: Calcium Receptor Selectivity

This example demonstrates that calcium receptors present on different cells exist as distinct subtypes which can be differentially affected by a particular drug. The parathyroid cell calcium receptor senses levels of
25 extracellular Ca²⁺ around 1.5 mM whereas the calcium receptor on the osteoclast responds to levels around 10 mM (Fig. 22). Neomycin or spermine, which activate the parathyroid cell calcium receptor, fail to affect the calcium receptors on C-cells or osteoclasts (Figs. 21 and 23).

30 These data constitute the first evidence for pharmacologically distinct subtypes of calcium receptors and these data are being used to design and develop drugs that act selectively on a particular type of calcium receptor. Indeed, testing of lead molecules demonstrate such cell-

specific effects. For example, Mg^{2+} , which increases $[Ca^{2+}]_i$ in bovine parathyroid cells ($EC_{50}=5$ mM), is without effect on $[Ca^{2+}]_i$ in osteoclasts even when tested at concentrations as high as 30 mM. Conversely, R-fendiline, which activates the parathyroid cell calcium receptor, is effective in activating the osteoclast calcium receptor only at concentrations 10-fold higher. Finally, agatoxin 489, although not very potent in activating the C-cell calcium receptor ($EC_{50} = 150$ μ M), is a quite potent activator of the parathyroid cell calcium receptor ($EC_{50} = 3$ μ M). The lead molecules presently under development will affect selectively the activity of a specific type of Ca^{2+} -sensing cell in vivo.

Drugs with less specificity might not necessarily be therapeutically undesirable. Thus, depressing osteoclast activity and stimulating calcitonin secretion are two different approaches to inhibiting bone resorption. Drugs that target the calcium receptors on both of these cells might be very effective therapies for osteoporosis. Because PTH is also involved in regulating bone metabolism, drugs acting on the parathyroid cell calcium receptor may also be useful in the treatment and/or prevention of osteoporosis.

Results of some test molecules are shown below. In Table 6, the comparative activity of calcimimetic molecules is shown. Bovine parathyroid cells and C-cells (rMTC 6-23 cells) were loaded with fura-2, and rat osteoclasts with indo-1 and the potency of the indicated molecules to mobilize intracellular Ca^{2+} determined by constructing cumulative concentration-response curves. Molecules listed as "inactive" did not alter $[Ca^{2+}]_i$ when tested at a concentration of 1 mM.

Table 6

COMPOUND	EC ₅₀ (μM)		
	PARATHYROID	OSTEOCLAST	C-CELL
5 NPS R-568	0.60	200	1.9
NPS S-568	30	---	---
NPS R-467	2	>100	2.2
NPS S-467	>30	---	---
NPS 017	6	inactive	150
10 R-Fendiline	9	150	---
Fendiline*	15	200	>100
NPS 015	22	---	inactive
NPS 019	40	>300	5
R-Prenylamine	7	150	6
15 1H*	30	250	---
Spermine	150	inactive	inactive
Neomycin	40	inactive	inactive

*racemic mixture; "inactive" is defined as causing no increase in cytosolic Ca²⁺ at a concentration of 1-5 mM.

Example 12: Lead Molecules for Parathyroid Calcium Receptor

Structure-activity studies using polyamines and arylalkyl polyamines led to the testing of molecules structurally akin to fendiline. Fendiline is a potent activator of the parathyroid cell calcium receptor. This molecule is notable because it possess only one positive charge, yet is much more potent than many polybasic molecules. Brief (2 min) pretreatment with PMA shifts the concentration-response curve for fendiline to the right. This indicates that fendiline acts through the same mechanism used by extracellular Ca²⁺ to activate the calcium receptor on parathyroid cells.

Fendiline evokes the mobilization of intracellular Ca^{2+} in *Xenopus* oocytes expressing the parathyroid cell calcium receptor, which demonstrates a direct action on the calcium receptor (Fig. 33). Moreover, fendiline contains a chiral carbon, and therefore exists in two isomeric forms. Both isomers have been synthesized and examined for activity. The *R*-isomer, *R*-fendiline, is 12 times more potent than the *S*-isomer, *S*-fendiline. This is the first demonstration that a calcium receptor can recognize an organic molecule in a stereospecific manner.

Because *R*-fendiline is a structurally simple molecule with selective and potent effects on the parathyroid cell calcium receptor, structure-activity studies around this lead molecule are simple. The aim of these studies is to generate an array of related molecules with various characteristics from which the final development candidate can be selected. This effort has already revealed some of the structural domains of *R*-fendiline that contribute to activity and potency. For example, the novel compound 1D is an analog of *R*-fendiline that is smaller ($\text{MW} < 240$), yet nearly as potent as the parent molecule, whereas several other analogues are relatively inactive. The most interesting molecules from this analog project can be put into *in vivo* testing for effects on PTH secretion and serum Ca^{2+} levels (see Examples 15, 16, 17, 18 and 23).

meta-Methoxyfendiline is another compound as potent as NPS 467 in causing the mobilization of intracellular Ca^{2+} in parathyroid cells. meta-Methoxyfendiline is a racemic mixture and it is anticipated that the resolution of meta-methoxyfendiline into its enantiomers will result in an isomer that is more potent than the racemic mixture.

The novel compound NPS 467 is an even smaller molecule than *R*-fendiline, yet the former is about 3-fold more potent than the latter in causing increases in $[\text{Ca}^{2+}]$ in parathyroid

cells. Like fendiline, NPS 467 is a racemic mixture. Resolution of NPS 467 into its enantiomers provides an isomer of even greater potency than the racemic mixture, i.e., NPS R-467 (see Example 17).

5 Further structure-activity studies on molecules related to R-fendiline, NPS 467, meta-methoxyfendiline and NPS 568 yielded pure isomers with greater potency than these molecules in their racemic forms. For example, the greater potency of NPS R-568 compared to NPS S-568 is shown in Figure 10 28b using different cells lines transfected with nucleic acid encoding a human parathyroid calcium receptor (pHuPCaR4.0)

Results obtained with fendiline (NPS 456, Fig. 33) show that it elicits oscillatory increases in Cl^- current at concentrations of 100 μM . The results obtained in this 15 expression system with neomycin and fendiline demonstrate that these molecules act directly on the calcium receptor but not on control cells. NPS R-568 has subsequently been shown to be the most potent molecule active on *Xenopus* oocytes expressing the parathyroid cell calcium receptor.

20 Results of testing some of the compounds shown in Figure 36 are provided in Tables 7 and 8. The measured EC_{50} values were determined by assaying for increases in intracellular calcium using fura-2 loaded cells (see Example 11 and Table 6).

25

TABLE 7

Examples of Arylalkylamine Compounds with *In Vitro* EC_{50} Values Greater than 5 μM at the Parathyroid Cell Calcium Receptor

30

Compound Name or Code (from Fig. 36)	EC_{50} (μM)
Fendiline (racemic)	15
R-Fendiline	9

	S-Fendiline	>15
	NPS S-467	>30
	NPS S-568	30
5	1A	166
	1B	776
	1C	126
	1D	48
	1E	123
	1S	128
10	2A	120
	7Y	>30
	7Z (R-)	>30
	7Z (S-)	>100
	8Y	>30
15	20K	>30
	20V	>100

TABLE 8

20 Arylalkylamine Calcimimetics from Figure 36 Active at the Parathyroid Cell Calcium Receptor *In Vitro* ($EC_{50} \leq 5 \mu M$)

	Compound Code (from Fig. 36)	EC_{50} (μM)	Compound Code (from Fig. 36)	EC_{50} (μM)
25	NPS R-467	2.0	11D	1.7
	NPS R-568	0.60	11X	0.83
	3U	0.64	11Y	2.8
	3V	1.8	12L	1.7
	4A	1.4	12U	1.2
	4B	2.0	12V	0.42
30	4C	2.0	12W	3.2
	4D	4.4	12Y	2.0

5	4G	1.8	13Q	ca. 0.8
	4H	≥ 3.0	13R	0.25
	4J	2.2	13S	< 0.13
	4M	2.1	13U	0.19
	4N	0.8	13X	< 0.75
10	4P	1.6	14L	0.26
	4R/6V	4.2	14Q	0.47
	4S	3.3	14U	0.13
	4T/4U	1.6	14V	1.7
	4V	2.5	14Y	0.38
15	4W	2.3	15G	ca. 0.5
	4Y	1.3	16Q	0.04
	4Z/5A	4.4	16R	0.36
	5B/5C	2.8	16T	0.04
	5W/5Y	3.6	16V	< 0.13
20	6E	2.7	16W	0.59
	6F (R, R-)	0.83	16X	0.10
	6R	3.4	17M	0.15
	6T	2.9	17O	0.04
	6X	2.5	17P	0.04
25	7W	3.2	17R	0.39
	7X	1.1	17W	0.43
	8D	2.5	17X	0.02
	8J	0.78	20F	< 1.0
	8K	1.3	20I	> 1.0
30	8R	2.6	20J	> 3.0
	8S	1.7	20R	2.4
	8T	1.8	20S	4.2
	8U	0.44	21D	3.0
	8X	0.76	21F	0.38

8Z	0.40	21G	1.1
9C	0.60	21O	0.26
9D	1.4	21P	0.43
9R	0.25	21Q	1.4
9S	4.8	21R	0.37
10F	0.89		

Example 13: Osteoclast Calcium Receptor Lead Molecules

10 The strategy used for elucidating the mechanism of action of extracellular Ca^{2+} on the osteoclast was similar to that proven effective in parathyroid cells. The first experiments examined the effects of La^{3+} on $[\text{Ca}^{2+}]_i$ in single rat osteoclasts loaded with the fluorimetric indicator indo-1. As described above, trivalent cations like La^{3+} are impermeant and block Ca^{2+} influx. Low micromolar concentrations of La^{3+} partially depressed extracellular Ca^{2+} -induced increases in $[\text{Ca}^{2+}]_i$ (Fig. 29). The demonstration of a La^{3+} -resistant increase in $[\text{Ca}^{2+}]_i$ provides evidence for the mobilization of intracellular Ca^{2+} . The results of these experiments parallel those obtained in parathyroid cells and suggest that similar mechanisms are used by extracellular Ca^{2+} to regulate $[\text{Ca}^{2+}]_i$ in both cell types.

25 Another series of experiments showed that extracellular Mn^{2+} evoked transient increases in $[\text{Ca}^{2+}]_i$ (Fig. 30(b)) that persisted in the absence of extracellular Ca^{2+} (Fig. 30(a)). These results are likewise indicative of the mobilization of intracellular Ca^{2+} . Although Mn^{2+} can enter some cells, it is unlikely to do so in the osteoclast because Mn^{2+} quenches the fluorescence of indo-1. Thus, if Mn^{2+} penetrated the cell, a decrease, not an increase in the fluorescent signal would be observed.

The results obtained with a variety of di- and trivalent cations are all consistent with the presence of a calcium receptor on the surface of the osteoclast that is coupled to the mobilization of intracellular Ca^{2+} and influx of extracellular Ca^{2+} through voltage-insensitive channels. Results show evidence for genetic material in human osteoclasts that encodes a calcium receptor protein (see below). Transient increases in $[\text{Ca}^{2+}]_i$ resulting from the mobilization of intracellular Ca^{2+} , are sufficient to inhibit osteoclastic bone resorption *in vitro*. Thus, as with the parathyroid cell, activation of the calcium receptor appears to be a viable means of inhibiting the activity of osteoclasts.

Prenylamine was examined for its ability to inhibit bone resorption *in vitro*. This was done by morphometric analysis of pit formation on thin slices of bovine cortical bone using scanning electron microscopy. Rat osteoclasts were incubated for 24 hours in slices of bone in the presence or absence of various concentrations of prenylamine. Prenylamine caused a concentration-dependent inhibition of bone resorption with an IC_{50} of 10 μM . The anticipated results provide the first demonstration that molecules acting at this novel site can inhibit osteoclastic bone resorption. More potent analogues of prenylamine will be generated using synthetic chemistry and will be tested and assayed using the methods described herein.

Example 14: C-Cell Calcium Receptor Lead Molecules

Activation of the C-cell calcium receptor stimulates the secretion of calcitonin which then acts on osteoclasts to inhibit bone resorption. Calcimimetic drugs selectively affecting C-cells are useful in the treatment of osteoporosis.

The mobilization of intracellular Ca^{2+} is used as a functional index of calcium receptor activity. The screening effort in C-cells is facilitated by the availability of cultured cell lines expressing the C-cell phenotype (e.g., rat medullary thyroid carcinoma cells; rMTC 6-23 cells). Selected for initial study were three naturally occurring arylalkyl polyamines, agatoxin 489, agatoxin 505, and NPS 019. Agatoxin 505 was found to block extracellular Ca^{2+} -induced increases in $[\text{Ca}^{2+}]_i$ with an IC_{50} of 3 μM . The inhibitory effect resulted from a block of the L-type voltage-sensitive Ca^{2+} channel present in these cells. In contrast, agatoxin 489 was found to mobilize intracellular Ca^{2+} in rMTC cells with an EC_{50} of 150 μM . This was the first organic molecule discovered that was found to activate the C-cell calcium receptor. NPS 019 was even more potent and mobilized intracellular Ca^{2+} with an EC_{50} of 5 μM (Fig. 32).

It is significant that the only structural difference between NPS 019 and agatoxin 489 is the presence or absence of an hydroxyl group. The fact that such subtle differences in structure affect profoundly the potency of molecules indicates a structurally specific binding site on the calcium receptor. This, in turn, encourages the view that very potent and selective activators of calcium receptors can be developed.

NPS 019, which is a small molecule ($\text{MW} < 500$), is a lead molecule for development of calcimimetics of the C-cell calcium receptor and can be tested for its ability to stimulate calcitonin secretion *in vitro*. Subsequent *in vivo* testing will then determine the ability of this molecule to stimulate calcitonin secretion and inhibit bone resorption. These *in vivo* studies will be performed in rats. The results obtained in these studies, which are anticipated to be positive, will provide the first evidence showing that a

small organic molecule acting on a novel receptor can stimulate calcitonin secretion and depress bone resorption.

Example 15: Calcilytic Activity of NPS 021 on Parathyroid Cells

For a compound to be considered a calcilytic, it must block the effects of extracellular Ca^{2+} or a calcimimetic compound on an extracellular Ca^{2+} -sensing cell. An example of a calcilytic compound is NPS 021, the structure of which is provided in Fig. 1a. In bovine parathyroid cells loaded with fura-2, NPS 021 blocks increases in $[\text{Ca}^{2+}]_i$ elicited by extracellular Ca^{2+} . The IC_{50} of NPS 021 for blocking this response is about 200 μM and, at concentrations around 500 μM , the increase in $[\text{Ca}^{2+}]_i$ evoked by extracellular Ca^{2+} is abolished. Significantly, NPS 021 does not by itself cause any change in $[\text{Ca}^{2+}]_i$ when tested at low $[\text{Ca}^{2+}]$ (0.5 mM; Fig. 37). Ga^{3+} is also calcilytic to *Xenopus* oocytes expressing the cloned calcium receptor: Ga^{3+} by itself has no effect on the Cl^- currents activated by Gd^{3+} , a calcimimetic, but pretreatment with Ga^{3+} blocks the action of Gd^{3+} .

Example 16: NPS 467 Lowers Serum Ionized Calcium

Compounds shown to activate the bovine parathyroid cell calcium receptor *in vitro* were tested for hypocalcemic activity *in vivo*. Male Sprague-Dawley rats (200 g) were maintained on a low calcium diet for one week prior to receiving test substance or vehicle as control. Blood was collected from the tail vein three hours after the intraperitoneal administration of NPS 467. Ionized Ca^{2+} in whole blood or serum was measured with a Ciba-Corning 634 Analyzer according to the instructions provided with the instrument. Serum total calcium, albumin and phosphate were measured by techniques well known in the art.

NPS 467 caused a dose-dependent reduction in serum or whole blood Ca^{2+} (Fig. 38). The fall in blood Ca^{2+} at this time was paralleled by a proportional fall in the levels of blood total calcium. There was no change in serum albumin or phosphate levels at any of the doses examined. In preliminary studies, NPS 467, at doses effective in lowering blood Ca^{2+} , caused a dose-dependent reduction in circulating levels of PTH (Fig. 39). The hypocalcemic effect of NPS 467 was maximal within three hours and returned toward control levels after 24 hours (Fig. 40).

NPS R-467 (see Example 17) was also effective in lowering serum ionized Ca^{2+} in rats maintained on a normal, calcium-replete diet. A single dose of NPS R-467 (10 mg/kg i.p.) caused a rapid fall in serum levels of ionized Ca^{2+} which were maximal by 1 hour (22% decrease from the control level) and remained depressed at or near this level for up to 6 hours.

Example 17: NPS 467 Lowers Serum Ionized Calcium in a Stereospecific Manner

NPS 467 is a racemic mixture. Resolution of NPS 467 into its two enantiomers was achieved by means of chiral HPLC. The R-isomer was about 100-fold more potent than the S-isomer in activating the bovine parathyroid cell calcium receptor *in vitro* as assessed by the ability of the enantiomers to evoke increases in $[\text{Ca}^{2+}]$ in parathyroid cells (Fig. 41). Likewise, similar resolution of the novel compound NPS 568 into its enantiomers showed that the R-isomer was 40-fold more potent than the S-isomer in causing the mobilization of intracellular Ca^{2+} in bovine parathyroid cells (see Table 6, *supra*).

The isomers of NPS 467 were examined for effects on serum Ca^{2+} as in Example 16. Consistent with the *in vitro* results, the R-isomer of NPS 467 proved to be more potent

than the S-isomer in lowering serum Ca^{2+} in vivo (Fig. 42; each compound was tested at a concentration of 5 mg/kg body weight).

5 Example 18: NPS R-467 Lowers Serum Ionized Calcium in an In Vivo Model of Secondary Hyperparathyroidism

An accepted and widely used animal model of secondary hyperparathyroidism arising from chronic renal failure is the 5/6 nephrectomized rat. Animals receiving such surgery
10 become initially hypocalcemic and, to maintain serum Ca^{2+} levels, there is a compensatory hyperplasia of the parathyroid glands and elevated levels of circulating PTH. Male Sprague-Dawley rats (250 g) received a 5/6 nephrectomy and were allowed to recover for 2 weeks. At this time they
15 were normocalcemic (due to elevated levels of serum PTH). The administration of NPS R-467 (10 mg/kg i.p.) caused a rapid (within 2 hours) fall in serum ionized Ca^{2+} levels to 83% of controls in an animal model of secondary hyperparathyroidism. This suggests that compounds of this
20 sort will effectively depress PTH secretion in patients with secondary hyperparathyroidism and hyperplastic parathyroid glands.

25 Example 19: NPS R-467 Fails to Lower Serum Ionized Calcium Levels in Parathyroidectomized Animals

To determine the primary target tissue upon which NPS R-467 acts to cause a hypocalcemic response, the parathyroid glands in rats were surgically removed. Animals receiving a total parathyroidectomy become hypocalcemic and are largely
30 dependent upon dietary calcium to maintain serum Ca^{2+} homeostasis. Parathyroidectomized animals had serum ionized Ca^{2+} levels of 0.92 mM which fell gradually to 0.76 mM after 6 hours of fasting. The administration of a single dose of NPS R-467 (10 mg/kg i.p.) did not cause any change in serum

ionized Ca^{2+} levels over a period of 6 hours. These results demonstrate that intact parathyroid glands are required for the hypocalcemic effects of NPS R-467. The data additionally demonstrate that NPS R-467 can target the parathyroid glands *in vivo*. The results are consistent with the view that NPS R-467 acts on the parathyroid cell calcium receptor *in vivo* to depress secretion of PTH and thereby cause serum levels of ionized Ca^{2+} to fall.

10 Example 20: NPS R-467 and NPS S-467 Increase Intracellular Calcium in Human Parathyroid Glands

Dissociated parathyroid cells were prepared from a parathyroid adenoma obtained by surgery from a patient with primary hyperparathyroidism. The cells were loaded with fura-2 and $[\text{Ca}^{2+}]_i$ measured as described above. Both NPS R-467 and NPS R-568 caused concentration-dependent increases in $[\text{Ca}^{2+}]_i$. The EC_{50} 's for NPS R-467 and NPS R-568 were 20 and 3 μM , respectively. Both of these compounds are thus able to increase $[\text{Ca}^{2+}]_i$ in pathological human tissue and would thus be expected to decrease serum levels of PTH and Ca^{2+} in patients with primary hyperparathyroidism.

Example 21: Mechanism of Action of NPS R-467 at the Parathyroid Cell Calcium Receptor

25 Dissociated bovine parathyroid cells were used to further explore the mechanism of action of NPS R-467 at the receptor level. In the presence of 0.5 mM extracellular Ca^{2+} , NPS R-467 caused a rapid and transient increase in $[\text{Ca}^{2+}]_i$ which persisted in the presence of 1 μM La^{3+} and was partially depressed by pretreatment with PMA (100 nM for 2 minutes). Moreover, 30 μM of NPS R-467 caused a rapid increase in Cl^- current in *Xenopus* oocytes injected with parathyroid cell mRNA. These results are consistent with an action of NPS R-467 on the calcium receptor. However, the

cytosolic Ca^{2+} response to NPS R-467 was abolished when parathyroid cells were suspended in Ca^{2+} -free buffer. This suggests that NPS R-467 cannot, by itself, cause the mobilization of intracellular Ca^{2+} . It does, however, elicit
5 responses in parathyroid cells and in oocytes when a small amount of extracellular Ca^{2+} is present. This suggests that partial occupancy of the Ca^{2+} -binding site is required for NPS R-467 to elicit a response.

To test this hypothesis, parathyroid cells were
10 suspended in Ca^{2+} -free buffer and exposed to a submaximal concentration of neomycin. Neomycin was used because it mimics, in nearly all respects, the effects of extracellular Ca^{2+} on parathyroid cells and on *Xenopus* oocytes expressing the parathyroid cell calcium receptor. The addition of 10 μM
15 neomycin did not by itself cause an increase in $[\text{Ca}^{2+}]_i$ under these conditions. However, the subsequent addition of NPS R-467 (30 μM) now elicited a transient increase in $[\text{Ca}^{2+}]_i$, which, because there was no extracellular Ca^{2+} present, must have come from the mobilization of intracellular Ca^{2+} .

20 When cells bathed in Ca^{2+} -free buffer were exposed to 30 μM NPS R-467, there was no increase in $[\text{Ca}^{2+}]_i$. This concentration of NPS R-467 is maximally effective in increasing $[\text{Ca}^{2+}]_i$ when extracellular Ca^{2+} (0.5 mM) is present. However, the subsequent addition of 10 μM neomycin now evoked
25 a transient increase in $[\text{Ca}^{2+}]_i$. Presumably, neomycin binds to the same site as extracellular Ca^{2+} and can functionally substitute for it. Using a submaximal concentration, which by itself causes no response, achieves partial occupancy of the Ca^{2+} -binding site and allows activation of the calcium
30 receptor by NPS R-467.

Additional studies to further define the mechanism of action of NPS R-467 were performed. The cells were once again suspended in Ca^{2+} -free buffer to insure that any observed increase in $[\text{Ca}^{2+}]_i$ resulted from the mobilization of

intracellular Ca^{2+} . In these experiments, however, a maximally effective concentration (100 μM) of neomycin was used. In the absence of extracellular Ca^{2+} , 100 μM neomycin evoked a rapid and transient increase in $[\text{Ca}^{2+}]_i$. The subsequent addition of 30 μM NPS R-467 did not cause an increase in $[\text{Ca}^{2+}]_i$.

In the converse experiment, 30 μM NPS R-467 was added before 100 μM neomycin. As expected, NPS R-467 did not cause any increase in $[\text{Ca}^{2+}]_i$. It did not, however, affect the increase in $[\text{Ca}^{2+}]_i$ evoked by the subsequent addition of 100 μM neomycin. These results, obtained with maximally effective concentrations of NPS R-467 and neomycin, suggest that these two compounds do not act at the same site. Rather, the results can be sufficiently explained by postulating two separate sites on the calcium receptor, one to which extracellular Ca^{2+} and neomycin bind, and another to which NPS R-467 and structurally related compounds (such as NPS R-568) bind.

Ligand binding to the former site can result in full activation of the calcium receptor whereas ligand binding to the latter site can only occur and/or be functionally relevant when the extracellular Ca^{2+} -binding site is occupied to some as yet undefined degree. It is possible that ligand binding to the extracellular Ca^{2+} -binding site exposes a previously occluded binding site for NPS R-467. It appears that the NPS R-467-binding site is an allosteric site that augments receptor activation in response to ligand binding at the extracellular Ca^{2+} binding site.

The data demonstrate that the parathyroid cell calcium receptor possesses at least two distinct sites for organic ligands. One site binds the physiological ligand, extracellular Ca^{2+} , and certain organic polycations like neomycin. Binding to this site results in full activation of the calcium receptor, an increase in $[\text{Ca}^{2+}]_i$, and the

inhibition of PTH secretion. NPS R-467 and NPS R-568 define a previously unrecognized binding site on the calcium receptor. Binding to this site can only occur and/or results in full activation of the calcium receptor when the
5 extracellular Ca^{2+} -binding site is partially occupied. Ligands acting at either site are effective in suppressing serum Ca^{2+} levels *in vivo*.

Allosteric Site on Parathyroid Cell Calcium Receptor

10 Calcimimetic compounds that activate the bovine parathyroid cell calcium receptor, such as NPS R-467 and NPS R-568, do not cause the mobilization of intracellular Ca^{2+} in the absence of extracellular Ca^{2+} . Rather, they increase the sensitivity of the calcium receptor to activation by
15 extracellular Ca^{2+} , thus causing a shift to the left in the concentration-response curve for extracellular Ca^{2+} . Because of this, it is unlikely that they act at the same site on the receptor as does extracellular Ca^{2+} . In contrast, organic and inorganic polycations do cause the mobilization of
20 intracellular Ca^{2+} in the absence of extracellular Ca^{2+} and therefore probably act at the same site as does extracellular Ca^{2+} . Compounds like NPS R-568, presumably act in an allosteric manner and their activity is dependent on some minimal level of extracellular Ca^{2+} . This suggests that
25 partial occupancy of the extracellular Ca^{2+} -binding site on the receptor is required for compounds like NPS R-568 to be effective. This model is consistent with the observations described in Example 21.

Other details of the mechanism of action of NPS R-568 on
30 the parathyroid cell calcium receptor, however, are more accurately investigated by binding studies in which the specific binding of radiolabeled (using ^3H for example) NPS R-568 is assessed. There are several molecular mechanisms that could explain the activity of NPS R-568 on the

parathyroid cell calcium receptor. In one mechanism (model 1), NPS R-568 could bind to the calcium receptor at a site that, when occupied, is not sufficient to activate the receptor functionally. Activation only occurs when some level of occupancy of the extracellular Ca^{2+} -binding site(s) is achieved. In an alternative mechanism (model 2), the occupation of the extracellular Ca^{2+} -binding site could unmask latent binding sites for compounds such as NPS R-568. Occupancy of this latent site by NPS R-568 then increases the affinity and/or efficacy of binding at the extracellular Ca^{2+} site. Either mechanism involves a form of allosteric activation of the calcium receptor by compounds such as NPS R-568. These are not the only possible mechanisms that could explain the effect of compounds like NPS R-568 on the parathyroid cell calcium receptor. Other mechanisms of action may be suggested by the results of the binding studies described below.

To further investigate the mechanism of action of compounds like NPS R-568 on the parathyroid cell calcium receptor, binding studies using ^3H -NPS R-568 can be performed. The specific binding of ^3H -NPS R-568 to intact parathyroid cells or to membranes prepared from parathyroid cells is initially investigated by techniques well known in the art. The kinetic parameters of binding will then be measured as a function of extracellular Ca^{2+} concentrations. Specifically, Scatchard analysis of the data will reveal the number of binding sites and the apparent affinity of the receptor site for ^3H -NPS R-568. These parameters will then be investigated as a function of changes in the level of extracellular Ca^{2+} in the buffer used for the assay. If model 1 is correct, then a significant level of specific binding should occur in the absence of extracellular Ca^{2+} . Large changes in the kinetic parameters of binding as a function of the level of extracellular Ca^{2+} would favor model

2. It is expected that various other inorganic and organic polycations described above in other examples will cause similar changes in the binding parameters of ^3H -NPS R-568 as does extracellular Ca^{2+} . This would support the view that these polycations act at the extracellular Ca^{2+} -binding site, which is distinct from that to which compounds like NPS R-568 bind.

Example 22: Synthesis and Chiral Resolution of NPS 467

- 10 This example describes a protocol used to synthesis NPS 467 and its resolution into individual enantiomers. In a 250-ml round-bottom flask, 10.0 g (100 mmoles) 3'-methoxyacetophenone and 13.5 g (100 mmoles) 3-phenylpropylamine were mixed and treated with 125 mmoles
15 (35.5 g) titanium(IV) isopropoxide. The reaction mixture was stirred 30 minutes at room temperature under a nitrogen atmosphere. After this time 6.3 g (100 mmoles) sodium cyanoborohydride in 100 ml ethanol was added dropwise over the course of 2 minutes. The reaction was stirred at room
20 temperature under nitrogen for 16 hours. After this time the reaction mixture was transferred to a 2-L separatory funnel with 1.5 L of diethyl ether and 0.5 L of water. The phases were equilibrated and the ether layer removed. The remaining aqueous phase was thoroughly extracted with four 1-L portions
25 of diethylether. The washes were combined, dried over anhydrous potassium carbonate and reduced to a clear, light amber oil.

- TLC analysis of this material on silica gel using chloroform-methanol-isopropylamine (100:5:1) showed product
30 at R_f 0.65 with traces of the two starting materials at R_f 0.99 (3'-methoxy acetophenone) and R_f 0.0 (3-phenylpropylamine).

The reaction mixture was chromatographed through silica gel (48 x 4.6 cm) using a gradient of chloroform-methanol-

isopropylamine (99:1:0.1) to (90:10:0.1) which yielded 13.66 g of purified NPS 467. This material was dissolved in hexane-isopropanol (99:1) containing 0.1% diethylamine to yield a solution with a concentration of 50 mg/ml. Chiral
5 resolution was accomplished by chromatography of 4 ml of this solution (200 mg, maximum to achieve separation) through ChiralCel OD (25 x 2 cm) using 0.7% isopropanol, 0.07% diethylamine in hexane at 10 ml/min, monitoring optical density at 260 nm.

10 Under these conditions (with injections of 100 mg material) the early-eluting isomer (NPS R-467; (R)-(+)-N-(3-phenylpropyl)- α -methyl-3-methoxybenzylamine) began to emerge from the column at about 26 minutes, the late-eluting isomer (NPS S-467) began to emerge at about 34 minutes. Baseline
15 resolution was accomplished under these conditions. Each optical isomer (free base) was converted to the corresponding hydrochloride salt by dissolving 3 g of the free base in 100 ml ethanol and treating it with 100 ml water containing 10 molar equivalents HCl. Lyophilization of these solutions
20 yielded white solids.

Example 22: Synthesis of NPS R-568

NPS R-568, (R)-(+)-N-[3-(2-chlorophenyl)propyl]- α -methyl-3-methoxybenzylamine, was synthesized using the
25 methods described in Example 22 substituting an equivalent amount of 3-(2-chlorophenyl)propylamine for 3-phenylpropylamine. It was found that allowing the mixture of 3'-methoxyacetophenone, 3-(2-chlorophenyl)propylamine and titanium(IV) isopropoxide to stir for 5 hours prior to
30 treatment with NaCNBH₃/EtOH resulted in significantly greater yield (98%).

Example 24: NPS R-467 Lowers Serum Ionized Calcium When Administered Orally

Rats (male, Sprague-Dawley, 250-300 g) were fed standard rat chow and fasted overnight prior to the experiment. NPS R-467 was suspended in corn oil and administered as a single oral dose through a gavage needle. Three hours later a sample of blood was taken from the tail vein and assessed for ionized Ca^{2+} levels. Fig. 44 shows that NPS R-467 caused a dose-dependent reduction in serum levels of ionized Ca^{2+} when administered orally.

Example 25: BoPCaR 1 Cloning Method

This example describes the cloning of a bovine parathyroid calcium receptor using an expression cloning strategy. The expression cloning strategy involved assaying the ability of nucleic acid to express a polypeptide which activates Cl^- currents in *Xenopus laevis* oocytes. *X. laevis* oocytes were chosen as hosts, to express nucleic acid encoding the bovine parathyroid calcium receptor, based on the following factors: (i) they exhibit a high level of maturity (i.e., Stage V, VI); (ii) they exhibit a high activity of Cl^- currents activated by Ca^{2+} ionophores like A23187; (iii) they exhibit a high level of functional expression of Gd^{3+} -induced Cl^- current when injected with 25 ng/oocyte of total poly(A)⁺-mRNA isolated from bovine parathyroid.

The techniques used to clone the parathyroid calcium receptor are briefly described in this example; a more complete description of the techniques is provided in preceding sections, which describe techniques which may be used to clone additional forms of the Ca^{2+} -receptor from other cell types. Poly(A)⁺-enriched mRNA was initially prepared from bovine parathyroid glands by extracting with guanidinium thiocyanate, centrifugation through CsCl and

oligo(dT) cellulose chromatography. Injection of the resultant poly(A⁺)-enriched mRNA into oocytes (25-50 ng/oocyte) conferred sensitivity to elevated extracellular concentrations of Ca²⁺ and the trivalent cation (1-100 μ M) Gd³⁺ as described herein, such that the two cations elicited calcium-activated chloride currents. No such currents were elicited in control eggs injected with water.

The mRNA was then subjected to size fractionation, utilizing preparative, continuous flow agarose gel electrophoresis (Hediger, M.A., Anal. Biochem. 159: 280-286 (1986)) to obtain fractions of poly(A⁺)-mRNA further enriched in transcripts coding for the Ca²⁺ receptor. Oocytes injected with size-fractionated mRNA of about 4-5.5 Kb showed enhanced expression of Gd³⁺-activated Cl⁻ currents.

Size-fractionated mRNA of about 4-5.5 Kb in size were used to prepare a size-selected, directional cDNA library in the plasmid pSPORT1 that was enriched in full-length transcripts. Sense complementary RNA (cRNA) was then synthesized from the DNA inserts pooled from 350-500 independent clones from this library and injected into oocytes. Gd³⁺-activated Cl⁻ currents were observed following injection of RNA from a single filter containing 350 colonies. Preparation and injection of cRNA from successively smaller pools of clones led to isolation of a single clone (BoPCaR 1) with a cDNA insert of 5.3 kb which expressed greatly enhanced Ca²⁺-receptor activity following injection of its cRNA into oocytes. A plasmid containing the BoPCaR 1 cDNA (See restriction map, Figure 45; plasmid, Figure 46; and nucleotide sequence (SEQ. ID. NO. 1), Figure 47) has been deposited in the ATCC under deposit number 75416.

The BoPCaR 1 cDNA is outside the size range of the size-selected RNA found to express neomycin elicited Cl⁻ channel activity in *Xenopus* oocytes. This is consistent with the

possibilities that different isoforms of the calcium receptor exist or that multiple genes encode other members of the calcium receptor gene family.

Several pharmacological and biochemical criteria were used to identify this clone as encoding a *bona fide* bovine parathyroid Ca^{2+} receptor. Oocytes expressing the cloned receptor, but not water-injected oocytes, responded to increasing concentrations of extracellular Ca^{2+} (1.5-5 mM) or Gd^{3+} (20-600 μM) with large increases in Cl^- currents (up to at least 1.8 microamperes) that were several-fold larger than those observed in poly(A^+)-injected oocytes. These responses increased markedly over a period of one to four days after injection of the eggs with cRNA prepared from the BoPCaR 1 cDNA. Furthermore, the ranges of the concentrations of the two cations eliciting this response were very similar to those shown previously to act on bovine parathyroid cells *in vitro*. Neomycin (20-100 μM), which is known to closely mimic the effects of Ca^{2+} on parathyroid cells, produced changes in Cl^- current in oocytes essentially identical to those produced by Ca^{2+} or Gd^{3+} , and these occurred over the same range of concentrations over which this antibiotic modulates parathyroid function *in vitro*.

Finally, *in vitro* translation of RNA prepared from the clone resulted in a single major protein on polyacrylamide gels with a molecular weight of about 120 kd, whose synthesis was enhanced by inclusion of dog pancreatic microsomes, concomitant with an increase in apparent molecular weight of 10-15%. The latter suggests that the cloned receptor interacts strongly with membranes, as might be expected of an integral membrane protein receptor, and is glycosylated in its native form. Studies with the lectin concanavalin A indicate that the Ca^{2+} receptor is likely a glycoprotein. Thus, the pharmacological properties of the cloned receptor, which is expressed at high levels in oocytes, as well as the

biochemical studies carried out to date are completely consistent with its identity as the bovine parathyroid Ca^{2+} receptor.

Oocytes injected with cRNA (50 nl of 0.125 $\mu\text{g}/\text{ml}$) prepared from BoPCaR1 show large inward currents in response to elevated extracellular concentrations of Ca^{2+} (5 mM), Mg^{2+} (10-20 mM), Gd^{3+} (600 μM), or neomycin (200 μM), resulting from activation of the Ca^{2+} -activated chloride currents. These responses are mediated by the following series of biochemical events:

(1) Activation of phospholipase C by a pertussis toxin-sensitive guanine nucleotide regulatory (G) protein resulting in 4-7 fold increases in the levels of inositol 1,4,5-triphosphate (IP_3). Preincubation with 10 $\mu\text{g}/\text{ml}$ of pertussis toxin for 48 hours inhibits the increase by 75%;

(2) Release of Ca^{2+} from intracellular stores. The several-fold increase in the $[\text{Ca}^{2+}]_i$ measured in oocytes loaded with the Ca^{2+} -sensitive fluorescent dye, fluo-3, persists even when the oocytes are exposed to Gd^{3+} or neomycin in the absence of extracellular Ca^{2+} . Furthermore, the inward currents elicited by Gd^{3+} or neomycin also persist despite removal of extracellular Ca^{2+} .

(3) The polyvalent cation-induced increases in $[\text{Ca}^{2+}]_i$ are necessary for the associated electrophysiological responses. The Ca^{2+} chelator, EGTA (100 μM), prevents oocytes expressing the calcium receptor from responding with inward currents to 600 μM Gd^{3+} .

(4) The activated currents appear to be Ca^{2+} -activated chloride currents. The currents are activated by the divalent cation ionophore, A23187, which raises $[\text{Ca}^{2+}]_i$. The chloride channel-blocker 9AC blocks the currents.

Example 26: Use of NPS R-568, and Other Compounds, as a Diagnostic Tool

NPS R-568 or other compounds active on a calcium receptor can be used as a diagnostic tool. Specifically, a pharmaceutical preparation of such compounds is useful as a diagnostic tool. In one example, a pharmaceutical preparation containing a parathyroid cell calcimimetic compound such as NPS R-568 can be given by oral or another route of administration to hypercalcemic patients with symptoms of mental depression. If these symptoms arise from an underlying hyperparathyroid state, such as primary hyperparathyroidism, then administration of NPS R-568 or a compound that acts similarly will alleviate those symptoms. If the symptoms do not abate, then the mental depression results from some pathological state that is not hyperparathyroidism. Thus, parathyroid cell calcimimetic compounds can be used in the differential diagnosis of mental depression.

Symptoms and signs common to hyperparathyroidism and other disorders can also be differentially diagnosed in the manner described above. Such shared signs and symptoms include, but are not limited to, hypertension, muscular weakness, and a general feeling of malaise. Alleviation of these symptoms following treatment with a parathyroid cell calcium receptor calcimimetic compound would indicate that the problems result from the underlying hyperparathyroidism.

In another example, a compound acting as an antagonist (calcilytic) at the C-cell calcium receptor can be administered as described above to diagnose medullary thyroid carcinoma. In this case, administration of the C-cell calcium receptor calcilytic compound will depress serum levels of calcitonin which can be readily measured by radioimmunoassay. Certain symptoms associated with medullary thyroid carcinoma, such as diarrhea, may also be monitored to

determine if they are abated or lessened following administration of the calcilytic compound.

In a third example, a compound acting as a calcimimetic at the juxtaglomerular cell calcium receptor can be used in the differential diagnosis of hypertension. In this case, administration of the juxtaglomerular cell calcium receptor calcimimetic compound can be carried out as described above. A decrease in blood pressure to normal levels will occur if the hypertension results mostly or exclusively from elevated levels of renin rather than from an alternative pathological state.

In another example, a compound acting as a specific calcimimetic on the osteoclast calcium receptor can be used in the differential diagnosis of high- and low-turnover forms of osteoporosis. In this case, such a compound can be administered in a suitable pharmaceutical preparation and the levels of serum alkaline phosphatase, osteocalcin, pyridinoline and/or deoxypyridinoline crosslinks, and/or some other predictive marker of bone resorption and/or formation measured by techniques well known in the art. A large decrease in one or more of these parameters would be predictive of high-turnover osteoporosis, whereas a small or no decrease in these parameters would be predictive of low-turnover osteoporosis. Such information would dictate the appropriate treatment. Antiresorptive drugs would not be the appropriate sole therapy for low-turnover osteoporosis.

These examples are not exhaustive but serve to illustrate that specific calcium receptors can be targeted with pharmaceutical preparations and that the observed effects of such preparations on bodily functions and/or chemical constituents can be used diagnostically. In general, calcimimetic and calcilytic compounds that act on calcium receptors of the various cells described above can be used in the diagnosis of the various diseases associated with

the particular cell type. These diseases include, but are not limited to, bone and mineral-related disorders (as described in Coe and Favus, Disorders of Bone and Mineral Metabolism, Raven Press, 1990), kidney diseases, endocrine diseases, cancer, cardiovascular diseases, neurological diseases, gastrointestinal diseases, and diseases associated with gestation. Examples of human diseases or disorders in which such molecules may be therapeutically effective are as follows:

10 (1) A calcimimetic is expected to ameliorate psoriasis by reducing the proliferation of the abnormal skin cells.

 (2) Since Ca^{2+} blocks the effect of vasopressin on MTAL and cortical collecting duct cells, a calcimimetic is expected to reduce water retention in states of vasopressin
15 excess, such as the syndrome of inappropriate vasopressin (ADH) secretion. Conversely, calcium receptor antagonists used in states of ADH deficiency are expected to potentiate the action of any ADH present, such as in partial central diabetes insipidus.

20 (3) Calcimimetics may be used to treat hypertension by:
 (a) reducing renin secretion and/or (b) by stimulating production of vasodilators such as PTHrP (PTH-related peptide) by vascular smooth muscle..

 (4) Calcimimetics are expected to increase platelet
25 aggregability, which may be useful when platelet counts are low. Conversely, calcilytics are expected to inhibit platelet function in states where there is hypercoagulability.

 (5) Calcium promotes differentiation of colon and
30 mammary cells. A calcimimetic is expected to reduce the risk of colon or breast cancer.

 (6) Calcium promotes urinary calcium excretion in the MTAL. A calcimimetic is expected to have a useful hypocalcemic action in the therapy of hypercalcemic

disorders. The inhibitory effect of calcimimetics on osteoclasts and their stimulation of the secretion of the hypocalcemic peptide calcitonin make them expected to be useful in the therapy of hypercalcemia and its symptoms. A
5 calcimimetic may also improve hypocalcemic symptoms by activating calcium receptors. Conversely, a calcilytic is expected to reduce urinary calcium excretion and be useful in the treatment of kidney stones. In addition, calcium suppresses the formation of 1,25-dihydroxyvitamin D in the
10 proximal renal tubule, and this vitamin D metabolite is frequently overproduced in renal stone patients and contributes to their hypercalciuria. Suppression of 1,25-dihydroxyvitamin D formation by a calcimimetic is expected to be useful in treating renal calcium stone disease.

15 (7) Endogenous amines could reproduce the symptoms in uremic patients by calcimimetic or calcilytic actions. Calcimimetic and/or calcilytic agents are expected to improve these symptoms.

(8) Some of the renal toxicity of aminoglycoside
20 antibiotics may be mediated by interaction of these drugs with renal calcium receptors. Having the calcium receptor is expected to make it possible to carry out drug screening easily when designing new drugs of these classes to minimize renal toxicity. In addition, a renal calcium receptor
25 antagonist would prevent or treat this renal toxicity if it is related to this mechanism.

(9) Some of the genetic component of calcium-related disorders, such as osteoporosis, renal stones, and hypertension are expected to be related to inherited problems
30 with certain forms of the receptor. These now can be studied and genetic screening/testing carried out using receptor-based reagents. The human disease, familial hypocalciuric hypercalcemia, may be due to a calcium receptor defect. Definitive diagnostic separation from cases of primary

hyperparathyroidism could be carried out with receptor-based technology.

- (10) Calcium receptors are present in the placenta and are expected to impact on disorders of placental function and transfer of nutrients to the growing fetus.

Example 27: Cloning of Human Parathyroid Calcium Receptor From a Human Parathyroid Gland Adenoma Tumor

This example describes the cloning of a human parathyroid calcium receptor from a human parathyroid gland adenoma tumor using pBoPCaR1 as a hybridization probe. The probe was used to identify nucleic acid encoding human parathyroid gland calcium receptor by cross-hybridization at reduced stringency.

Messenger RNA was prepared from a human parathyroid gland adenoma tumor removed from a 39-year-old Caucasian male diagnosed with primary hyperparathyroidism. Northern blot analysis of this mRNA using pBoPCaR1 as a hybridization probe identified calcium receptor transcripts of about 5 Kb and about 4 Kb. A cDNA library was constructed from the mRNA. Double-stranded cDNA larger than 3 Kbp were size-selected on an agarose gel and ligated into the cloning vector lambda ZapII. Five hundred thousand primary recombinant phage were screened with the 5.2 Kbp cDNA insert of pBoPCaR1 as a hybridization probe. The pBoPCaR1 insert was labeled by random-primed synthesis using [³²P]-dCTP to a specific activity of 1×10^9 cpm/ μ g.

Library screening was performed at a hybridization stringency of 400 mM Na⁺, 50% formamide at a temperature of 38°C. Plaque lift filters were hybridized at a probe concentration of 500,000 cpm/ml for 20 hours. Following hybridization, filters were washed in 1 x SSC at 40°C for 1 hr.

The primary screen identified about 250 positive clones identified by hybridization to pBoPCaR1. Seven of these clones were taken through secondary and tertiary screens to isolate single clones that hybridized to the pBoPCaR1 probe.

5 These seven clones were analyzed by restriction enzyme mapping and Southern blot analysis. Three of the clones contained cDNA inserts of about 5 Kbp and appear to be full-length clones corresponding to the 5 Kb mRNA. Two of the clones contain cDNA inserts of about 4 Kbp and appear to be

10 full-length clones corresponding to the 4 Kb mRNA.

Restriction enzyme mapping of the two different sized inserts indicate that they share regions of sequence similarity in their 5' ends, but diverge in their 3' end sequences. DNA sequence analyses indicate that the smaller

15 insert may result from alternative polyadenylation upstream of the polyadenylation site used in the larger insert.

Representative cDNA inserts for both size classes were subcloned into the plasmid vector pBluescript SK. Linearization followed by *in vitro* transcription using T7 RNA

20 polymerase produced cRNA transcripts. The cRNA transcripts were injected into *Xenopus* oocytes (150 ng/ μ l RNA; 50 nl/oocyte) for functional analysis. Following incubation periods of 2-4 days, the oocytes were assayed for the presence of functional calcium receptors. Both clone types

25 gave rise to functional calcium receptors as assessed by the stimulation of calcium-activated chloride currents upon addition of appropriate calcium receptor agonists. Known calcium receptor agonists, including NPS R-467 and NPS R-568, activated the oocyte-expressed receptor at about the same

30 concentrations known to be effective for the native parathyroid cell receptor. Thus, both clones encode a functional, human parathyroid cell calcium receptor.

Plasmids were prepared by subcloning each size class of insert into pBluescript thereby producing pHuPCaR 5.2 and

pHuCaR 4.0. The nucleic acid sequence, and amino acid sequence, of the inserts are shown in Figures 48 (pHuPCaR 5.2, SEQ. ID. NO. 2) and 49 (pHuPCaR 4.0, SEQ. ID. NO. 3).

Several differences were observed between the nucleic acid sequences of the two cDNA inserts. Sequence analyses of the two cDNA inserts indicate the existence of at least two sequence variants differing in the 3' untranslated region and which may result from alternative polyadenylation (see SEQ. ID. NOS. 2 and 3). In addition, sequence variation exists at the 5' end of the inserts (see SEQ. ID. NOS. 2 and 3). These distinct sequences correspond to untranslated regions and may have arisen due to alternative transcriptional initiation and/or splicing.

Three additional sites of sequence variation are observed within the coding regions of cDNA clones pHuPCaR4.0 and pHuPCaR5.2 (see SEQ. ID. NOS. 2 and 3) demonstrating that these cDNA clones encode distinct proteins. Sequence analysis of the human CaR gene (obtained from overlapping clones as described in Example 29) indicates that the additional 30 base pairs of DNA in cDNA clone pHuPCaR5.2, as compared to the pHuPCaR 4.0 cDNA clone, results from alternative mRNA splicing. The alternative mRNA splicing is predicted to insert 10 additional amino acids into the CaR polypeptide encoded by the pHuPCaR5.2 cDNA at a site between aa#536 and aa#537 in polypeptide encoded by pHuPCaR4.0 cDNA. In addition, pHuPCaR4.0 encodes glutamine (Gln) at aa#925 and glycine (Gly) at position 990 whereas pHuPCaR5.2 encodes arg (Arg) at both equivalent positions. The human CaR gene encodes for Gln and Arg, respectively, at these positions. The difference between the pHuPCaR4.0 cDNA compared to human DNA appears to represent a true sequence polymorphism within the human population while the single base change in pHuPCaR5.2 probably reflects a mutation which occurred during its cloning. Both cDNAs encode functional calcium receptors

as demonstrated by the ability of *Xenopus* oocytes injected with cRNA prepared from these cDNA clones to respond to 10 mM extracellular calcium as ascertained by Cl⁻ conductance. However, it is possible that these two receptor isoforms are functionally and/or pharmacologically distinct.

Example 28: Cloning a Calcium Receptor From Normal Human Parathyroid Tissue

This example describes the cloning of a calcium receptor from normal human parathyroid tissue. Experimental evidence has shown that parathyroid cells from adenomatous tissue are less responsive to increases in extracellular calcium (they have an elevated calcium "set-point"). It has been postulated that this change may arise from an alteration of the calcium receptor itself. One of the uses of the cloned receptor found in normal parathyroid tissue is to compare its primary nucleic acid sequence with that of the calcium receptor found in adenomatous tissue to determine if there are any differences in the nucleic acid sequences. Such differences may account for the alteration in the calcium receptor and may be used to further characterize regions of the calcium receptor associated with responsiveness to calcium.

Parathyroid glands (150 mg) were removed at autopsy from a 69-year-old Caucasian female with no history of parathyroid disease. Messenger RNA was prepared from this tissue and used in the construction of a cDNA library. cDNA inserts from this library were not size-selected. Six-hundred-thousand primary recombinants were screened with probe made from the 5.2 Kbp cDNA insert from the human calcium receptor clone, pHuPCaR-5.2. Hybridization was carried out at 42°C and filters were washed at a stringency of 1 x SSC, at 52°C. The primary screen identified about 30 positive clones, twelve of which were isolated and characterized. Partial

sequence analysis indicated that these clones are essentially identical to cDNA sequences obtained from adenomatous parathyroid (see Example 27).

5 Example 29: Isolation of Human Genomic Clones With Homology to the Calcium Receptor

Human calcium receptor genomic clones were isolated using the pBoPCaR1 cDNA insert as a hybridization probe. In particular, a human genomic DNA library, obtained from
10 Stratagene, was screened using the pBoPCaR1 cDNA insert as hybridization probe.

A portion of the library (500,000 clones) was screened with the pBoPCaR1 cDNA insert by hybridizing in 400 mM Na⁺, 50% formamide, at 37°C, and washing with 1 x SSC at 40°C.
15 Twenty-four clones were identified. The nucleic acid from these clones were analyzed by restriction mapping and Southern blot analysis using distinct regions of the pHuPCaR-5.2 cDNA insert as hybridization probes. Nine of the 13 clones encoded portions of the human parathyroid calcium
20 receptor gene as evinced by hybridization to pHuPCaR-5.2 cDNA. The complete gene is represented on overlapping clones pHuCaR-#4, #5, #6, #7 and #9. DNA sequence analysis of these clones indicates that the receptor is encoded by seven coding exons. The majority of the receptor mRNA (3' end) appears to
25 be encoded by a single exon. The receptor encoded by these genomic clones is essentially identical to those encoded by cDNA clones pHuPCaR4.0 and pHuPCaR5.2 (Seq. ID. Nos. 2 and 3) (see Example 27, *supra*, which describes the differences between the human nucleic acid sequence obtained from
30 overlapping clones pHuCaR-#4, #5, #6, #7 and #9, pHuPCaR4.0 and pHuPCaR5.2). Equivalent clones can be isolated as described herein, as can other clones encoding members of this receptor family.

Example 30: Cloning Ion Receptors From the Kidney

This example describes the cloning of ion receptors from rat kidney cells using pBoPCaR1 as a hybridization probe. A cDNA library was prepared from rat kidney outer medulla mRNA size-fractionated to contain transcripts between 3 and 7 Kb. About seventy-five-thousand clones were screened using pBoPCaR1 as a hybridization probe at 42°C overnight followed by washing in 0.5 x SSCP at 42°C. Three positive clones were identified.

Clone 3A (pRakCaR 3A) contained an insert of about 4.0 Kbp. The nucleic acid and amino acid sequence of the 3A insert is shown in Figure 50 (SEQ. ID. NO. 8). Northern analysis indicated that pRakCaR 3A hybridized to both 7.5 Kb and 4.0 Kb transcripts. DNA sequence analysis of clone 3A (SEQ. ID. No. 4) indicates that it is highly homologous to other calcium receptor sequences. *Xenopus* oocyte analysis of *in vitro* transcripts of the clone confirmed that clone pRakCaR 3A encodes a functional calcium receptor.

Example 31: Cloning of C-cell Calcium Receptor

This example describes the cloning of human thyroid C-cell calcium receptor using pHuPCaR 5.2 as a hybridization probe. Functional evidence indicates that the calcitonin-secreting C-cells of the thyroid gland express a calcium receptor. Pharmacological evidence indicates that this receptor is functionally distinct from the parathyroid calcium receptor. Northern blot analysis of human, bovine and rat thyroid gland mRNA identifies a faintly hybridizing transcript when pHuPCaR-5.2 is used as hybridization probe. The diminished intensity of the identified transcript may be due either to low abundance (C-cells represent 0.01% to 1% of thyroid cells) or may indicate structural differences between parathyroid and C-cell calcium receptors.

Northern blot analysis of a rat C-cell line (44-2) using a rat calcium receptor genomic clone as hybridization probe identifies a single, moderately abundant transcript about 8.0 Kb. This is similar to the size of the rat parathyroid calcium receptor transcript and provides evidence that C-cells express a calcium receptor. DNA sequence analysis of products from polymerase chain reaction amplification of selected regions of the rat C-Cell calcium receptor showed it to be essentially identical to the calcium receptor encoded by the rat kidney cDNA clone of Example 31 (Figure 50).

A human C-cell calcium receptor was cloned from a thyroid cDNA library obtained from Clontech. The library was prepared from tissue obtained at autopsy from normal Caucasian males (trauma victims; no history of thyroid disease). About five-hundred-thousand recombinant phage were screened at a stringency of 400 mM Na⁺, 50% formamide at a temperature of 40°C, and filters were washed at 1 x SSC, 42°C. Four cDNA clones hybridizing with pHuPCaR-5.2 were obtained. Insert sizes ranged from 0.8 to 2 Kbp. Initial sequence analysis indicates that this calcium receptor sequence is highly homologous to the human parathyroid calcium receptor. Equivalent clones can be readily isolated as described herein.

25 Example 32: Cloning Inorganic ion Receptors by Use of Degenerate Sequence PCR

Analysis of the calcium receptor sequences (bovine and human) by sequence database comparison indicates that the calcium receptor sequence is unique. No significant homology is obvious to any known protein or nucleic acid sequence with one exception. The parathyroid calcium receptor exhibits weak, but significant homology (20-30% amino acid identity) with the metabotropic glutamate receptors (mGluRs). This surprising and unexpected result indicates that calcium

receptors are structurally related to mGluRs and probably evolved from a common ancestral gene several hundred million years ago. However, calcium receptors are functionally distinct from mGluRs and in experiments on bovine parathyroid
 5 cells, or on *Xenopus* oocytes ectopically expressing calcium receptors, did not respond to the mGluR agonists glutamate, trans-ACPD and quisqualate.

The discovery of the calcium receptor sequence makes it possible to determine regions of extremely high sequence
 10 conservation. Such regions are useful for guiding the preparation of hybridization and PCR probes which can be used to detect and isolate cDNA and genomic sequences encoding additional related receptors such as inorganic ion receptors.

Analysis of the amino acid sequences of calcium
 15 receptors and mGluRs indicates that the homology is highest in several limited regions including portions of both N-terminal putative extracellular domains and the seven-transmembrane domain regions. Based on the later, four degenerate oligonucleotides have been synthesized for use in
 20 PCR. These are:

TM2:

CCTGCTCGAGACIA (A, G) (C, T) CGGGA (A, G) CT (C, T) T (C, G) CTA (C, T)
 (C, A) T;

TM5:

25 CGGAATTCCGTTICGGG (A, T) (C, T) TTGAA (C, G) GC (A, G) (A, T) A (G, C) ;

CL1:

CCTGCTCGAGTCAAGGCTACG (A, G) (A, G) I (C, A) G (G, A, C, T) GA (G, A) (C, T) T;

and, CL3:

CGGAATTCCATTTGGCTTCGTTGAAI (T, G) T (A, G, C, T) (G, T) C (G, A, T, C) GG.

30 These oligonucleotides contain XhoI or EcoRI restriction sites within "PCR anchors" at their 5' ends to facilitate subcloning of the amplification products. The sequences were selected based on conservation of sequences within transmembrane domains 2 and 5 and cytoplasmic loops 1 and 3.

Four different primer combinations can be used to obtain ion receptor clones: TM2 + TM5, TM2 + CL3, CL1 + TM5, and CL1 + CL3. PCR reactions were carried out using standard conditions (see, e.g., Abe et al. J. Biol. Chem., 19:13361 (1992)) using annealing temperatures between 37°C and 55°C. Each combination gave rise to products approximately 500 bp when used to amplify cDNAs or genomic DNAs containing ion receptors and/or mGluRs. Libraries of such PCR products have been prepared after amplification of such sequences from cDNAs prepared from a variety of tissues, and from genomic DNA. Analysis of the products resulted in the detection of parathyroid calcium receptor sequences, 5 mGluR sequences and additional sequences which are being characterized. The additional new sequences may encode other inorganic ion receptors.

This example, like the other examples described herein, is not meant to be limiting. Various other highly conserved sequence regions can be identified and utilized in a similar fashion. Such advances are made possible by the discovery of the parathyroid calcium receptor sequence, as will be recognized by those of ordinary skill in the art. The cloning of such PCR products enables the isolation of complete genomic clones and of full-length cDNA clones from the tissue sources identified by, for example, Northern analysis using the cloned PCR product. As additional members of this family are discovered and their sequences determined, refinement of this approach will be possible. Thus, the invention herein enables the discovery of more and more members of this receptor family via an iterative process.

Example 33: Antibodies Against Calcium Receptors

Cloned human and bovine calcium receptors can be used to produce antibodies which recognize various regions of the

receptor including extracellular domains, cytoplasmic domains, extracellular loops and cytoplasmic loops. Recombinant expression of three regions of the N-terminal extracellular domain has been achieved. In particular, GST
 5 fusion products have been produced containing amino acids 9-258 and 259-334, respectively, of the bovine parathyroid calcium receptor and amino acids 340-620 from the human parathyroid calcium receptor. These fusion products were isolated by preparative SDS-PAGE and injected into rabbits
 10 resulting in polyclonal antibodies against the putative extracellular domain.

In addition, the following synthetic peptides have been produced by Multiple Peptide Systems, Inc:

- SEQ. ID. NO. 9: YKDQDLKSRPESVEC,
- 15 SEQ. ID. NO. 10: ADDDYGRPGIEKFREEAEERDIC,
- SEQ. ID. NO. 11: CIDFSELISQYSDEEKIQQ,
- SEQ. ID. NO. 12: YHNGFAKEFWETFNFC,
- SEQ. ID. NO. 13: DGEYSDETDASAC,
- SEQ. ID. NO. 14: NTPIVKATNRELSYC,
- 20 SEQ. ID. NO. 15: YRNHELEDEIIFITC, and
- SEQ. ID. NO. 16: RKLPEFNEAKYC.

These amino acid sequence are based upon regions of the bovine parathyroid calcium receptor.

These peptides were conjugated to KLH and injected into
 25 rabbits to produce polyclonal antibodies or injected into mice to produce monoclonal antibodies. Such antibodies are capable of recognizing specific regions of the bovine parathyroid calcium receptor and most would be expected to recognize calcium receptors from other species including
 30 human calcium receptors. Highly acidic peptides (e.g., SEQ. ID. NOs. 9-12 and 15), derived from acid-rich regions of the calcium receptor may be involved in binding to calcium ion. It is expected, therefore, that such antibodies will be

5 Example 34: Recombinant Expression of Parathyroid Calcium Receptors in Vertebrate Cells

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(4) The plasmid CMVHuPCaR4.0 was constructed by subcloning the HindIII-NotI 4.0 Kbp fragment from human calcium receptor cDNA into HindIII-NotI cut pcDNAI/Amp.

(5) The plasmid CMVHuPCaR5.2 was constructed by subcloning the HindIII-NotI 5.2 Kbp fragment from human calcium receptor cDNA into HindIII-NotI cut pcDNAI/Amp.

(6) The plasmid pSV-HuPCaR4.0 was constructed by subcloning the SalI-NotI 4.0 Kbp fragment from human calcium receptor cDNA into SalI-NotI cut pcDNAI/Amp.

(7) The plasmid pSV-HuPCaR5.2 was constructed by subcloning the SalI-NotI 5.2 Kbp fragment from human calcium receptor cDNA into SalI-NotI cut pcDNAI/Amp.

The above expression vectors were first validated for correct construction by *in vitro* transcription and injection into *Xenopus* oocytes. All were found to elicit expression of functional calcium receptors.

Next, these vectors were transfected into a variety of vertebrate cells including: COS7, CHO, DHFR-CHO, HEK293, JEG, Rat2 fibroblasts, MDBK, CV1, UMR, AtT20, Y1, OK, LLC-PK1. Several different transfection techniques were used including calcium phosphate precipitation, DEAE-dextran, electroporation and lipofection. All the transfected cell lines gave rise to substantial levels of calcium receptor transcript.

Functional calcium receptor expression was assessed by loading cells with fura-2 and measuring changes in intracellular calcium levels after addition of calcium receptor agonists. Control constructs were prepared by cloning the substance K receptor and the M1 muscarinic receptor cDNAs into similar commercial vectors as described above. Control constructs were transfected into the various cell lines described above, and the response of the cells containing the control constructs to substance K or to carbachol, respectively, was measured. Classical responses

the Calcium Receptor

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The pMSG subclone containing the HuPCaR 5.2 insert was transfected into CHO cells as discussed above. Selection has

resulted in 20 resistant clones which are being characterized. The Cep4B subclone containing the HuPCaR 5.2 insert was transfected into HEK293 cells as described above. Selection with hygromycin resulted in a pool of stable clones. Clones expressing the HuPCaR 4.0 receptor isoform were prepared similarly.

Cells obtained from the pool of hygromycin selected HEK293 cells transfected with Cep4B containing the HuPCaR 5.2 insert were plated on collagen coated Aclar squares which had been placed into individual wells of 12-well tissue culture plates. Two to six days later, medium was removed and the cells washed with balanced salt solution and 1 ml of buffer containing 1 μ M fura2-AM, 1 mM CaCl_2 and 0.1% BSA and 1 mM CaCl_2 . Measurements of fluorescence in response to calcium receptor agonists were performed at 37°C in a spectrofluorimeter using excitation and emission wavelengths of 340 and 510 nm, respectively. For signal calibration, F_{max} was determined after addition of ionomycin (40 μ M) and the apparent F_{min} was determined by addition of 0.3 M EGTA, 2.5 M Tris-HCl; pH 10. Robust increases in intracellular calcium were observed in response to the addition of the following calcium receptor agonists: Ca^{2+} (10 mM), Mg^{2+} (20 mM) and NPS R-467. Control cells expressing functional substance K receptors did not respond to these calcimimetic compounds.

Additional clonal isolates of HEK 293 cells transfected with pHuPCaR4.0 sequence were obtained. These were tested for responsiveness to calcimimetics as described above except that the cells were tested while in suspension. Similar positive results were obtained (Fig. 28b).

Example 36: Activity of NPS R-568 in Xenopus Oocytes Expressing a Bovine Parathyroid Cell Calcium Receptor

Xenopus oocytes were injected with BoPCaR 1, the 5.3 Kb cDNA encoding a bovine parathyroid cell calcium receptor as described in Example 25. After two to three days, Cl⁻ currents were examined in the oocytes using a two-electrode voltage clamp. In the presence of 0.3 or 1 mM extracellular Ca²⁺, exposure of BoPCaR 1-injected oocytes to NPS R-568 caused increases in the Cl⁻ current. The EC₅₀ for NPS R-568 in this assay was about 3 μM. NPS R-568 failed to evoke responses in uninjected oocytes or in oocytes injected with water or rat liver mRNA. NPS S-568 elicited responses in BoPCaR 1-injected oocytes only at much higher concentrations (100 μM). The results of these experiments demonstrate that NPS R-568 acts in a stereoselective manner in oocytes expressing a bovine parathyroid cell calcium receptor. The data are consistent with a direct action of NPS R-568 on the calcium receptor.

The Cl⁻ current response to NPS R-568 in oocytes expressing BoPCaR 1 was abolished in the absence of extracellular Ca²⁺. Increasing the concentration of extracellular Mg²⁺ to 4 mM (in the absence of extracellular Ca²⁺) restored responsiveness to NPS R-568. NPS R-568 potentiated the responses to submaximal concentrations of extracellular Ca²⁺ and shifted the extracellular Ca²⁺ concentration-response curve to the left without greatly affecting the maximal response (Fig. 51). These effects obtained in oocytes expressing a parathyroid cell calcium receptor mirror those obtained in intact bovine parathyroid cells and offer compelling evidence for a direct effect of NPS R-568 on a parathyroid cell calcium receptor.

The data are also consistent with NPS R-568 increasing the sensitivity of the receptor through an allosteric mechanism by binding to a domain on the calcium receptor distinct from that which binds extracellular Ca²⁺. Alternatively, NPS R-568, although binding at the

extracellular Ca^{2+} domain, may lack intrinsic efficacy unless the domain is partially occupied by extracellular Ca^{2+} . The more likely hypothesis is the former, in which NPS R-568 acts through an allosteric mechanism to increase the sensitivity of the receptor to activation by extracellular Ca^{2+} .

The failure of NPS R-568 to elicit responses in the absence of extracellular Ca^{2+} demonstrates that partial occupancy of the calcium receptor by extracellular Ca^{2+} is necessary for NPS R-568 to activate the receptor. It is not presently known if NPS R-568 binds to the calcium receptor in the absence of extracellular Ca^{2+} or if binding of extracellular Ca^{2+} to the calcium receptor unmasks a cryptic binding site for NPS R-568. These alternative hypotheses can be readily resolved by direct binding studies using ^3H -NPS R-568 as described above under the heading of "Allosteric Site on Parathyroid Cell Calcium Receptor."

Example 37: Activity of Arylalkyl Polyamines in *Xenopus* Oocytes Expressing a Bovine Parathyroid Cell Calcium Receptor

Xenopus oocytes were injected with BoPCaR 1 as described in Example 25. After two to three days, Cl^- currents were examined in the oocytes using two electrode voltage clamp. In the presence of 1 mM extracellular Ca^{2+} , exposure of BoPCaR 1-injected oocytes to the arylalkyl polyamine compounds NPS 017 (shown as AGA 489 in Fig. 1f) or NPS 019 caused oscillatory increases in the Cl^- current. Increases in Cl^- current evoked by NPS 019 persisted in the absence of extracellular Ca^{2+} . Neither NPS 017 nor NPS 019 elicited changes in Cl^- current in uninjected oocytes or in oocytes injected with water or rat liver mRNA.

The results provide compelling evidence for a direct action of arylalkyl polyamine compounds on a parathyroid cell calcium receptor. In authentic bovine parathyroid cells, arylalkyl polyamine compounds mobilize intracellular Ca^{2+} in

the absence of extracellular Ca^{2+} ; they have identical effects in oocytes expressing a bovine parathyroid cell calcium receptor. Also, like the inorganic di- and trivalent cations, the arylalkyl polyamines are positively charged. In the aggregate, the results suggest that the arylalkyl polyamines act at the same site on the calcium receptor as does extracellular Ca^{2+} .

These data also distinguish the action of arylalkyl polyamines like NPS 019 from arylalkylamines like NPS R-568 (see Example 36). These two classes of compounds have different mechanisms of action on the parathyroid cell calcium receptor and probably bind at different domains on the receptor. For example, while arylalkyl polyamines can stimulate the parathyroid calcium receptor in the absence of extracellular Ca^{2+} , NPS R-568 requires the presence of extracellular Ca^{2+} or an appropriate agonist, such as an arylalkyl polyamine, to stimulate the receptor. Arylalkyl polyamines can completely restore responses to NPS R-568 in the absence of extracellular Ca^{2+} . Moreover, NPS R-568 shifts the concentration-response curve of NPS 019 to the left.

Arylalkyl polyamines mimic, in all respects tested, the actions of extracellular divalent cations and are true calcimimetic compounds. Arylalkyl polyamines therefore define a new structural class of calcimimetic compounds that act through a different mechanism than compounds like NPS R-568, probably by binding to a different domain on the calcium receptor. Arylalkyl polyamines can be used as structural templates for drugs useful in the treatment of various bone and mineral-related disorders.

Example 38: Analogs of Arylalkyl Polyamines and Polyamines Useful as Antagonists of Calcium Influx in Parathyroid Cells

Arylalkyl polyamines such as NPS 019 and polyamines such as spermine act as calcimimetics at the parathyroid cell calcium receptor presumably by binding to the extracellular Ca^{2+} -binding domain on the receptor (Examples 2, 6 and 36).

5 Certain structural analogs of the arylalkyl polyamines or polyamines, in which the secondary amines are replaced by methylenes, act as blockers of Ca^{2+} influx in parathyroid cells. NPS 384 and NPS 472 (1,12-diaminododecane, see Fig. 1a) are arylalkyl polyamine and polyamine analogs,
10 respectively, lacking secondary amines. When tested at high micromolar concentrations (100 to 1000 μM), either of these compounds causes a prompt fall in $[\text{Ca}^{2+}]_i$ in bovine parathyroid cells bathed in buffer containing 2 mM CaCl_2 . Pretreatment of parathyroid cells with either of these
15 compounds depresses steady-state, but not transient increases in $[\text{Ca}^{2+}]_i$ elicited by increasing the concentration of extracellular Ca^{2+} . In both these respects, the effects of NPS 384 and NPS 472 are similar to low concentrations of La^{3+} or Gd^{3+} which block Ca^{2+} influx.

20 Structural analogs of NPS 384 and NPS 472 with greater potency for blocking Ca^{2+} influx in parathyroid cells can be synthesized by modification of the aromatic moiety or alkyl chain. Compounds that block the influx of extracellular Ca^{2+} in parathyroid cells may find therapeutic utility in the
25 treatment of various bone and mineral-related disorders. For example, it is known that the level of extracellular Ca^{2+} can regulate the mRNA levels for PTH. Thus, blocking the influx of extracellular Ca^{2+} may increase mRNA levels for PTH. Such an increase in mRNA transcripts would be expected to increase
30 PTH synthesis, resulting in a larger reserve of PTH for secretion. Calcilytic compounds might therefore cause an augmented release of PTH when administered after a drug that blocks influx of extracellular Ca^{2+} in parathyroid cells.

Example 39: Activity of NPS R-568 and Arylalkyl Polyamines in *Xenopus* Oocytes Expressing a Human Parathyroid Cell Calcium Receptor

Xenopus oocytes were injected with pHuPCaR 5.2, the 5.2
5 Kb cDNA encoding a parathyroid cell calcium receptor derived
from a human parathyroid cell adenoma. (See Example 27.)
After two to three days, Cl^- currents were measured in the
oocytes using a two-electrode voltage clamp. In the presence
of 0.3 mM extracellular Ca^{2+} , both NPS R-568 or NPS 019 (3 to
10 30 μM) evoked increases in the Cl^- current indicating
activation of the expressed calcium receptor. In the absence
of extracellular Ca^{2+} , the response to NPS 019 persisted
whereas that to NPS R-568 was abolished. In *Xenopus* oocytes
expressing a human parathyroid cell calcium receptor, NPS R-
15 568 shifted the concentration-response curve to the left
without greatly altering the maximal response. Thus, a human
parathyroid cell calcium receptor responds to NPS R-568 and
to NPS 019 similarly to bovine parathyroid cells.

20 Example 40: Activity of NPS R-467 and NPS R-568 on C-Cells

C-cells appear to express a calcium receptor that is
structurally similar to that present on parathyroid cells
(see Example 31). The effects of NPS R-467 and NPS R-568 on
[Ca^{2+}]_i in a rat medullary thyroid carcinoma C-cell line (44-2
25 cells) were examined. In the presence of extracellular Ca^{2+}
(1 mM), either compound evoked a concentration-dependent
increase in [Ca^{2+}]_i. Both compounds were less potent on C-
cells than bovine parathyroid cells. The EC_{50} , for NPS R-467
and NPS R-568 were 1.9 and 2.2 μM , respectively. Thus,
30 compounds in this structural series appear to activate the C-
cell calcium receptor.

Arylalkyl polyamines likewise elicit increases in [Ca^{2+}]_i
in C-cells as they do in parathyroid cells (see Examples 6
and 13). Some arylalkyl polyamines are more potent on C-

cells than on parathyroid cells. Thus, compounds structurally related to NPS R-568, but with greater potency on C-cells compared to parathyroid cells, may reside in the compound library illustrated in Fig. 36. Compounds more
5 potent on C-cells than parathyroid cells could be used to selectively increase calcitonin secretion while having little or no effect on PTH secretion.

Example 41: NPS R-568 Increases Calcitonin Secretion In Vivo

10 Normal adult Sprague-Dawley rats were administered various doses of NPS R-568 p.o. At various times following the administration of NPS R-568, blood samples were withdrawn and measured for PTH, ionized Ca^{2+} , and calcitonin. NPS R-568 caused a rapid, dose-dependent decrease in the plasma
15 levels of PTH and Ca^{2+} and an increase in calcitonin. The ED_{50} values for the depression of PTH and Ca^{2+} and stimulation of calcitonin were 1, 8 and 40 mg/kg p.o. Thus, the oral administration of NPS R-568 suppresses plasma levels of PTH at doses lower than those which increase plasma levels of
20 calcitonin.

In subsequent studies, rats received a thyroidectomy (parathyroid glands intact). This surgical procedure effectively removed the C-cells secreting calcitonin and therefore enabled the relative contributions of PTH and
25 calcitonin to the hypocalcemic effect of this compound to be determined. In thyroidectomized animals, the administration of NPS R-568 (3 to 100 mg/kg p.o.) caused a hypocalcemic response equal in magnitude to that produced in sham-operated animals. The only difference was that the rate of onset of
30 the hypocalcemic response was somewhat delayed in thyroidectomized animals. Thus, the major action of NPS R-568 causing the hypocalcemic response is an inhibition of PTH secretion. Stimulatory effects of this compound on

calcitonin secretion increases the rate of onset, but not the extent, of hypocalcemia.

Example 42: Effectiveness of NPS R-568 in Humans

- 5 NPS R-568 was studied in a placebo-controlled, single-dose, dose-escalation format in a healthy, post-menopausal woman. A range of single oral doses was used to assess safety, tolerance, and changes in primary hyperparathyroidism markers (e.g., plasma concentrations of parathyroid hormone and ionized serum calcium) and of serum calcitonin. The data are shown in Tables 8-10.

Table 8

Effect of NPS R-568 on Serum Parathyroid Hormone in a Human

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TIME (hours)								
DOSE	6	0.5	1	2	4	8	12	24
Serum PTH (pg/ml)								
Placebo	34	32	32	34	32	36	44	32
20 mg	31	23	18	24	34	34	48	32
240 mg	29	18	6	6	10	27	35	34
400 mg	33	13	9	8	11	20	31	31

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Table 9Effect of NPS R-568 on Serum Ionized Calcium in a Human

DOSE	TIME (hours)							
	0	0.5	1	2	4	8	12	24
Serum Ionized Calcium (mg/dl)								
Placebo	1.26	1.23	1.24	1.24	1.25	1.23	1.18	1.23
20 mg	1.26	1.26	1.26	1.26	1.26	1.26	1.23	1.29
240 mg	1.26	1.26	1.25	1.23	1.19	1.16	1.18	1.23
400 mg	1.24	1.26	1.25	1.22	1.19	1.13	1.15	1.22

Table 10Effect of NPS R-568 on Serum Calcitonin in a Human

DOSE	TIME (hours)							
	0	0.5	1	2	4	8	12	24
Serum Calcitonin (pg/ml)								
Placebo	3.5	4.0	3.8	4.2	3.9	3.6	3.3	3.4
20 mg	3.2	3.8	3.2	4.5	4.2	3.9	3.2	3.6
240 mg	5.8	4.8	6.5	7.5	6.1	4.7	5.3	8.3
400 mg	3.4	4.0	6.0	7.1	5.2	3.8	3.7	3.0

The data illustrated in Tables 8-10 indicate that NPS R-568 causes a transient dose-dependent decrease in plasma PTH concentration (Table 8), and, at higher doses, a decrease in serum ionized calcium concentration (Table 9) in the human subject. There was no apparent change in serum calcitonin at

the doses studied (Table 10). Higher doses are expected to affect calcitonin levels as observed in rats (see Example 41).

5 Examples 43-54

Examples 43 to 54 describing the syntheses of compounds 4L, 8J, 8U, 9R, 11X, 12U, 12V, 12Z, 14U, 17M and 17P, are provided below. Compounds 4L, 8J, 8U, 11X and 17M were prepared from the condensation of a primary amine with an aldehyde or ketone in the presence of titanium(IV) isopropoxide. The resulting intermediate imines were then reduced *in situ* by the action of sodium cyanoborohydride, sodium borohydride, or sodium triacetoxyborohydride. The intermediate enamine for the synthesis of compound 8U was catalytically reduced using palladium hydroxide.

Compounds 9R, 14U, and 17P were synthesized by reductive amination of a commercially available aldehyde or ketone with a primary amine in the presence of sodium cyanoborohydride or sodium triacetoxyborohydride. It was found for the syntheses of these three compounds (9R, 14U, and 17P) that sodium triacetoxyborohydride afforded the desired diastereomers with greater diastereoselectivity than using sodium cyanoborohydride. The enriched mixtures were further purified to a single diastereomer by normal-phase HPLC or by recrystallization.

Compounds 12U, 12V and 12Z were prepared by a diisobutylaluminum hydride (DIBAL-H)-mediated condensation of an amine with a nitrile. The resulting intermediate imine is reduced *in situ* by the action of sodium cyanoborohydride or sodium borohydride. The intermediate alkenes (compounds 12U and 12V) were reduced by catalytic hydrogenation in EtOH using palladium on carbon. Compounds which were converted to their corresponding hydrochlorides were done so by treatment of the free base with ethereal HCl to afford white solids.

The starting materials for these syntheses were: (1) purchased from Aldrich Chemical Co., Milwaukee, WI, (2) purchased from Celgene Corp., Warren, NJ, or (3) prepared synthetically using standard techniques known in the art.

5 All other reagent chemicals were purchased from Aldrich Chemical Co.

Example 43: Synthesis of Compound 4L

N-3-Phenyl-1-propyl-1-(1-naphthyl)ethylamine

10 A mixture of 3-phenyl-1-propylamine (135 mg, 1 mmol), 1'-acetonephthone (170 mg, 1 mmol), and titanium (IV) isopropoxide (355 mg, 1.3 mmol) was stirred at room temperature for 1 hour. The reaction was treated with 1 M ethanolic sodium cyanoborohydride (1 mL) and stirred at room

15 temperature for 16 hours. The reaction was diluted with ether and treated with water (0.1 mL). The reaction was centrifuged and the ether layer removed and concentrated to a milky oil. A small portion of this material (10 mg) was purified by HPLC (Phenomenex, 1.0 x 25 cm, 5- μ M silica) using

20 a gradient of dichloromethane to 10% methanol in dichloromethane containing 0.1% isopropylamine. This afforded the product (free base) as a single component by GC/EI-MS (R_f = 10.48 min) m/z (rel. int.) 289 (M^+ , 11), 274 (63), 184 (5), 162 (5), 155 (100), 141 (18), 115 (8), 91

25 (45), and 77(5).

Example 44: Synthesis of Compound 8J

N-(3-Phenylpropyl)-1-(3-thiomethylphenyl)ethylamine hydrochloride

30 3'-Aminoacetophenone (2.7 g, 20 mmol) was dissolved in 4 mL of concentrated HCl, 4 g of ice and 8 mL of water. The solution was cooled to 0°C, and sodium nitrite (1.45 g, 21 mmol) dissolved in 3-5 mL of water was added over 5 minutes while maintaining the temperature below 6°C. Sodium

thiomethoxide (1.75 g, 25 mmol) was dissolved in 5 mL of water and cooled to 0°C. To this solution was added the diazonium salt over 10 minutes while maintaining the temperature below 10°C. The reaction was stirred for an additional hour while allowing the temperature to rise to ambient. The reaction mixture was partitioned between ether and water. The ether layer was separated and washed with sodium bicarbonate and sodium chloride, and dried over sodium sulfate. The ether was evaporated to give a 74% yield of 3'-thiomethylacetophenone. The crude material was purified by distillation at reduced pressure.

3-Phenylpropylamine (0.13 g, 1 mmol), 3'-thiomethylacetophenone (0.17 g, 1 mmol), and titanium (IV) isopropoxide (0.36 g, 1.25 mmol) were mixed together and allowed to stand for 4 hours. Ethanol (1 mL) and sodium cyanoborohydride (0.063 g, 1 mmol) were added and the reaction was stirred overnight. The reaction was worked up by the addition of 4 mL of ether and 200 μ L of water. The mixture was vortexed and then spun in a centrifuge to separate the solids. The ether layer was separated from the precipitate, and the solvent removed *in vacuo*. The oil was redissolved in dichloromethane and the compound purified by preparative TLC on silica gel eluted with 3% methanol-dichloromethane to yield the title compound as a pure oil: GC/EI-MS (R_f =7.64 min) m/z (rel. int.) 285 (M^+ , 18), 270 (90), 180 (17), 151 (100), 136 (32), 104 (17), 91 (54), and 77 (13).

Example 45: Synthesis of Compound 8U

(R) - (+) - N-3 - (2-Methoxyphenyl) - 1-propyl - 3-methoxy- α -methylbenzylamine hydrochloride

A mixture of (R) - (+) - 3-methoxy- α -methylbenzylamine (3.02 g, 20 mmol), 2-methoxycinnamaldehyde (3.24 g, 20 mmol), and titanium (IV) isopropoxide (8.53 g, 30 mmol, 1.5 eq.) was stirred for 2 hours at room temperature and treated with 1 M

(20 mL) ethanolic sodium cyanoborohydride. The reaction was stirred overnight (16 hours), diluted with diethyl ether, and treated with water (1.44 mL, 80 mmol, 4 eq.). After mixing for 1 hour, the reaction mixture was centrifuged and the ether layer removed and concentrated to an oil. This material was dissolved in glacial acetic acid, hydrogenated at 60 p.s.i. hydrogen in the presence of palladium hydroxide for 2 hours at room temperature. The catalyst was removed by filtration and the resulting solution concentrated to a thick oil. This material was dissolved in dichloromethane and neutralized with 1 N NaOH. The dichloromethane solution was separated from the aqueous phase, dried over anhydrous potassium carbonate and concentrated to an oil. This material was dissolved in ether and treated with 1 M HCl in diethylether. The resulting precipitate (white solid) was collected, washed with diethyl ether, and air dried. GC/EI-MS (R_t = 9.69 min) of this material (free base) showed a single component: m/z (rel. int.) 299 (M^+ , 21), 284 (100), 164 (17), 150 (8), 135 (81), 121 (40), 102 (17), 91 (43), and 77 (18).

Example 46: Synthesis of Compound 9R

(R,R)-N-(1-(2-Naphthyl)ethyl)-1-(1-naphthyl)ethylamine hydrochloride

A mixture of (R)-(+)-1-(1-naphthyl)ethylamine (10.0 g, 58 mmol), 2'-acetonaphthone (9.4 g, 56 mmol), titanium (IV) isopropoxide (20.7 g, 73.0 mmol), and EtOH (abs.) (100 mL) was heated to 60°C for 3 hours. Sodium cyanoborohydride (NaCNBH_3) (3.67 g, 58.4 mmol) was then added. The reaction mixture was stirred at room temperature for 18 hours. Ether (1 L) and H_2O (10 mL) were added to the reaction mixture and the resulting precipitate was removed by centrifugation. The supernatant was evaporated under vacuum and the crude product was recrystallized four times from hot hexane, to provide 1.5

g of pure (98+%) diastereomer. The free base was dissolved in hexane, filtered, and then ethereal HCl was added to precipitate the product as a white solid (1.1 g, 6% yield), m.p.: softens 200-240°C (dec.).

5

Example 47: Synthesis of Compound 11X

(R)-N-(4-Isopropylbenzyl)-1-(1-naphthyl)ethylamine hydrochloride

A mixture of (R)-(+)-1-(1-naphthyl)ethylamine (1.06 g, 6.2 mmol), 4-isopropylbenzaldehyde (0.92 g, 6.2 mmol), and titanium (IV) isopropoxide (2.2 g, 7.7 mmol) was heated to 100°C for 5 min then allowed to stir at room temperature for 4 hours. Sodium cyanoborohydride (NaCNBH₃) (0.39 g, 6.2 mmol) was then added followed by EtOH (1 mL). The reaction mixture was stirred at room temperature for 18 hours. Ether (100 mL) and H₂O (1 mL) were added to the reaction mixture and the resulting precipitate was then removed by centrifugation. The supernatant was evaporated under vacuum and the crude product was chromatographed on silica gel (50 mm X 30 cm column) (elution with 1% MeOH/CHCl₃). The chromatographed material was then dissolved in hexane and ethereal HCl was added to precipitate the product as a white solid (0.67 g, 35% yield); m.p. 257-259°C.

25 Example 48: Synthesis of Compound 12U

(R)-N-3-(2-Methylphenyl)-1-propyl-3-methoxy- α -methylbenzylamine hydrochloride

A solution of 2-methylcinnamionitrile (1.43 g, 10 mmol) in dichloromethane (10 mL) was cooled to 0°C and treated dropwise (15 minutes) with 1 M diisobutylaluminum hydride (10 mL, dichloromethane). The reaction was stirred for at 0°C for 15 minutes and treated dropwise (15 minutes) with a 1 M solution of (R)-(+)-3-methoxy- α -methylbenzylamine (1.51 g, 10 mmol) in dichloromethane (10 mL). The reaction was stirred

for 1 hour at 0°C and poured into a solution of ethanol (100 mL) containing sodium cyanoborohydride (1 g, 16 mmol). The reaction mixture was stirred 48 hours at room temperature. The reaction was diluted with diethyl ether and neutralized
5 with 1 N NaOH. The diethyl ether layer was removed, dried over anhydrous potassium carbonate and concentrated to an oil. This material was chromatographed through silica using a gradient of dichloromethane to 5% methanol in dichloromethane to afford the unsaturated intermediate, a
10 single component by GC/EI-MS (R_t = 10.06 min) m/z (rel. int.) 281 (M^+ , 17), 266 (59), 176 (19), 146 (65), 135 (73), 131 (100), 91 (21), and 77 (13).

The unsaturated intermediate in ethanol was hydrogenated (1 atm H_2) in the presence of palladium on carbon for 16
15 hours at room temperature. The product from this reaction was converted to the hydrochloride salt by treatment with 1 M HCl in diethyl ether. GC/EI-MS (R_t = 9.31 min) of this material (free base) showed a single component: m/z (rel. int.) 283 (M^+ , 21), 268 (100), 164 (12), 148 (8), 135 (85),
20 121 (12), 105 (49), 91 (23), and 77 (21).

Example 49: Synthesis of Compound 12V

(R)-N-3-(3-Methylphenyl)-1-propyl-3-methoxy- α -methylbenzylamine hydrochloride

25 The compound was prepared following the procedure described in Example 48, but using 2-methylcinnamitrile. The unsaturated intermediate was a single component by GC/EI-MS (R_t = 10.21 min) m/z (rel. int.) 281 (M^+ , 57), 266 (86), 146 (98), 135 (88), 131 (100), 115 (43), 102 (26), 91 (43),
30 and 77 (18). Reduction of this material and hydrochloride formation using the procedure described in Example 48 afforded the product. GC/EI-MS (R_t = 9.18 min) of this material (free base) showed a single component; m/z (rel.

int.) 283 (M^+ , 19), 268 (100), 164 (11), 148 (8), 135 (76), 121 (16), 105 (45), 91 (23), and 77 (21).

Example 50: Synthesis of Compound 12Z

5 (R)-N-3-(2-Chlorophenyl)-1-propyl-1-(1-naphthyl)ethylamine hydrochloride

The compound was prepared following the procedures described in Example 48, but using 2-chlorohydrocinnamionitrile and (R)-(+)-1-(1-naphthyl)ethylamine on a 10-mmol scale. Chromatography through silica gel using a gradient of dichloromethane to 5% methanol in dichloromethane afforded the product as a single component by silic gel TLC analysis (5% methanol in dichloromethane). The hydrochloride was prepared by 15 treatment with 1 M HCl in diethyl ether.

Example 51: Synthesis of Compound 14U

(R,R)-N-(1-(4-Methoxyphenyl)ethyl)-1-(1-naphthyl)ethylamine hydrochloride

20 A mixture of (R)-(+)-1-(1-naphthyl)ethylamine (1.1 g, 6.2 mmol), 4'-methoxyacetophenone (0.93 g, 6.2 mmol), titanium (IV) isopropoxide (2.2 g, 7.7 mmol), and EtOH (abs.) (1 mL) was heated to 60°C for 3 hours. Sodium cyanoborohydride (NaCNBH_3) (0.39 g, 6.2 mmol) was then added, 25 and the reaction mixture was stirred at room temperature for 18 hours. Ether (200 mL) and H_2O (2 mL) were added to the reaction mixture and the resulting precipitate was then removed by centrifugation. The supernatant was evaporated under vacuum and the crude product was chromatographed on 30 silica gel (25 mm X 25 cm column) (elution with 1% MeOH- CHCl_3). A portion of this material was HPLC chromatographed [Selectosil, 5- μM silica gel; 25 cm x 10.0 mm (Phenomenex, Torrance, CA), 4 mL per minute; UV det. 275 nm; 12% ethyl acetate-88% hexane (elution time, 12.0 min)]. The HPLC

purified diastereomer was then dissolved in hexane and ethereal HCl was added to precipitate the product as a white solid (20 mg), m.p. 209-210°C (dec.).

5 Example 52: Synthesis of Compound 17M

(R)-N-(3-Chloro-4-methoxybenzyl)-1-(1-naphthyl)ethylamine hydrochloride

A mixture of (R)-(+)-1-(1-naphthyl)ethylamine (6.6 g, 39 mmol), 3'-chloro-4'-methoxybenzaldehyde (6.6 g, 39 mmol),
10 titanium (IV) isopropoxide (13.8 g, 48.8 mmol), and EtOH (abs.) (30 mL) was heated to 80°C for 30 minutes and then stirred at room temperature for 3 hours. Sodium cyanoborohydride (NaCNBH₃) (2.45 g, 39 mmol) was then added and the reaction mixture was stirred at room temperature for
15 an additional 18 hours. Diethyl ether (100 mL) and H₂O (2 mL) were then added to the reaction mixture and the resulting precipitate was removed by centrifugation. The supernatant was evaporated under vacuum and the crude product was chromatographed on silica gel (50 mm X 30 cm column) (elution
20 with CH₂Cl₂). The chromatographed material was then dissolved in hexane (500 mL), decolorized with Norit®, filtered (0.2 μM), and then ethereal HCl was added to precipitate the product as a white solid (10.2 g, 56% yield), m.p. 241-242°C (dec.).

25

Example 53: Synthesis of Compound 17P

4-Methoxy-3-methylacetophenone [17P Precursor]

A mixture of 4'-hydroxy-3'-methylacetophenone (5.0 g, 33.3 mmol), iodomethane (5.7 g, 40.0 mmol), K₂CO₃ (granular, anhydrous) (23.0 g, 167 mmol), and acetone (250 mL) was
30 refluxed for 3 hours. The reaction mixture was then cooled to room temperature, filtered to remove the inorganic salts, and evaporated under vacuum. The crude product was dissolved in ether (100 mL) and washed with H₂O (2 x 20 mL). The

organic layer was dried (Na_2SO_4) and evaporated to yield 4.5 g, 82.4% yield. The ketone was used in the following reaction without further purification.

5 (R,R)-N-(1-(4-Methoxy-3-methylphenyl)ethyl)-1-(1-naphthyl)ethylamine hydrochloride [Compound 17P]

A mixture of (R)-(+)-1-(1-naphthyl)ethylamine (4.24 g, 24.8 mmol), 4'-methoxy-3'-methylacetophenone (4.06 g, 24.8 mmol), titanium (IV) isopropoxide (8.8 g, 30.9 mmol), and
10 EtOH (abs.) (1 mL) was heated to 100°C for 2 hours. Isopropanol (45 mL) was added and the reaction was cooled to 10°C in an ice bath. Sodium triacetoxyborohydride $\text{NaHB}(\text{O}_2\text{CCH}_3)_3$, 10.5 g, 49.5 mmol was then added in portions over 15 minutes. The reaction mixture was then heated to
15 70°C for 18 hours. The mixture was cooled to room temperature and poured into ether (400 mL). The suspension was centrifuged, the supernatant was collected and the pellet was washed with ether (400 mL). The combined organic washings were evaporated under vacuum. The residue was
20 dissolved in ether (400 mL) and washed with 1 N NaOH (4 x 50 mL) and H_2O (2 x 50 mL). The organic layer was dried (Na_2SO_4), filtered and evaporated under vacuum. EtOH (abs.) was added to the wet residue, which was then dried thoroughly on a rotary evaporator to provide an oil. The mixture was
25 then chromatographed on silica gel (50 mm x 30 cm) [elution with (1% MeOH-1% isopropylamine- CHCl_3) to give 4.8 g of an oil].

The desired diastereomer was further purified by HPLC chromatography [SUPELCOSIL™ PLC-Si, 18- μM silica gel; 25 cm
30 x 21.2 mm (Supelco, Inc., Bellefonte, PA), 7 mL per minute; UV det. 275 nm: 20% EtOAc-80% hexane (elution time 9.5 - 11.0 min)]. Injections (800- μL aliquots) of the mixture (100 mg/mL solution in eluent) provided 65 mg of the desired isomer. Multiple HPLC injections provided 1.0 g of purified

material. The HPLC-chromatographed material was dissolved in hexane (50 mL) and the hydrochloride salt was precipitated with ethereal HCl. The salt was collected on fritted glass and washed with hexane to provide 1.0 g of a white solid, mp
5 204-205°C.

Example 55: SYNTHESIS OF COMPOUND 17X

3-Chloro-4-methoxybenzaldehyde

A mixture of 3-chloro-4-hydroxybenzaldehyde (25 g, 160
10 mmol), iodomethane (27.25 g, 192 mmol), K_2CO_3 (granular, anhydrous) (110.6 g, 800 mmol), and acetone (300 mL) was refluxed for 3 hours. The reaction mixture was then cooled to room temperature. Diethyl ether (500 mL) was added and the mixture was filtered through paper to remove the
15 inorganic solids. the filtrate was evaporated under reduced pressure, dissolved in diethyl ether (800 mL), and washed with 0.1 N NaOH (3 x 100 mL). The organic layer was dried (Na_2SO_4) and evaporated under vacuum to yield 24 g, 92% yield of crude product. This material was further purified by
20 chromatography on silica gel (50 mm x 30 cm) (elution with hexane-EtOAc, 5:1) to give 15.02 g, 56% yield of a white solid: TLC (hexane-EtOAc, 5:1) R_f =0.24; GC R_t =4.75 min; MS (EI) m/z 170 (M^+), 172 ($M+2$).

25 1-Methyl-(3'-chloro-4'-methoxybenzyl) alcohol

A mixture of 3-chloro-4-methoxybenzaldehyde (13 g, 76.5 mmol), methylmagnesium chloride (52 g, 153 mmol), and THF (300 mL) was refluxed for 3 hours. The reaction mixture was cooled to room temperature. NH_4Cl (satd. soln., 6 mL) was
30 added dropwise followed by diethyl ether (500 mL) and the mixture was filtered through paper to remove the inorganic solids. The filtrate was evaporated under reduced pressure and the resulting solid was dissolved in diethyl ether (300 mL) and washed with water (4 x 25 mL). The organic layer was

dried (Na_2SO_4) and evaporated under vacuum to yield 11.3 g, 80% yield of crude product. This material was further purified by chromatography on silica gel (50 mm x 30 cm) (elution with CH_2Cl_2) to yield 11.3 g, 63% yield of an oil;
 5 TLC (CH_2Cl_2) $R_f=0.25$; GC $R_t=5.30$ min; MS (EI) m/z 186(M^+), 188($\text{M}+2$).

3'-Chloro-4'-methoxyacetophenone

A mixture of 1-methyl-(3'-Chloro-4'-methoxybenzyl)
 10 alcohol (7.6 g, 41 mmol), pyridinium chlorochromate (PCC) (13.16 g, 61.5 mmol), and CH_2Cl_2 (300 mL) was allowed to stir at room temperature for 2 hours. Diethyl ether (1000 mL) was added and the resulting mixture was placed on a chromatography column of silica gel (50 mm x 30 cm) (elution
 15 with diethyl ether) to yield 7.3 g, 97% yield of crude solid product. GC analysis of this material showed it to be 99% pure and it was used in the following reaction without further purification. TLC (diethyl ether) $R_f=1.0$; GC $R_t=5.3$ min; MS (EI) m/z 184(M^+), 184($\text{M}+2$).

20

(R,R)-N-(1-Ethyl-4'-methoxy-3'-chlorophenyl)-1-(1-naphthylethyl)amine

A mixture of 3'-chloro-4'-methoxyacetophenone (5.3 g, 29 mmol), (R)-(+)-1-(1-naphthyl)ethylamine (4.98 g, 29 mmol),
 25 titanium (IV) isopropoxide (10.2 g, 36 mmol), and isopropanol (20 mL) was heated to 100°C for 3 hours. Sodium triacetoxyborohydride ($\text{NaB}(\text{O}_2\text{CCH}_3)_3$; 12.29 g, 58 mmol) was added in portions over 10 minutes. The reaction mixture was heated to reflux for 30 minutes and was then allowed to stir at room
 30 temperature for 18 hours. The mixture was then poured into diethyl ether (500 mL); H_2O (2 mL) was added and the suspension was centrifuged to remove the fine precipitate of titanium salts. The supernatant was collected and the pellet was washed with ether (500 mL). The combined organic layers

were dried (Na_2SO_4) and evaporated under vacuum to yield 6.81 g, 70% of crude product.

This material was further purified by chromatography on silica gel (50 mm x 30 cm) (elution with 3% MeOH-97% CH_2Cl_2) to give 2.01 g of an oil. The diastereomer was further purified by recrystallization. The free base (1.98 g) was converted to its HCl salt with ethereal HCl. This salt was dissolved in hot isopropanol (65 mL) and the solution was filtered through paper. The filtrate was evaporated under vacuum and the resulting solid dissolved in isopropanol (30 mL). After standing at room temperature for 18 hours, the crystalline solid was collected, washed with cold isopropanol (20 mL), and dried to yield 0.87 g, 40% (from free base) of the diastereomerically pure hydrochloride salt: mp 236-237°C (dec); TLC (MeOH- CH_2Cl_2 [99:1]) R_f =0.25; GC R_t =11.06 min; FTIR (KBr pellet, cm^{-1}) 3433, 2950, 2931, 2853, 2803, 2659, 2608, 2497, 1604, 1595, 1504, 1461, 1444, 1268, 1260, 1067, 1021, 802, 781, 733; MS (EI) m/z 339(M^+), 341($M+2$).

Other embodiments are within the following claims.